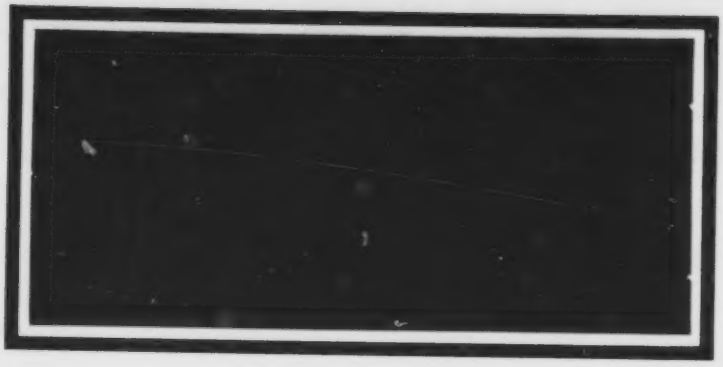

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FINAL REPORT

STUDY OF HARMONIC REDUCTION ALTERNATIVES FOR THE NSTF SOLAR SIMULATOR

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TABLE OF CONTENTS

		Page Number
	ACKNOWLEDGEMENTS	(i)
1.	EXECUTIVE SUMMARY	1
2.	RESUME	2
3.	INTRODUCTION AND BACKGROUND	3
4.	OBJECTIVES	4
5.	METHOD	5
6.	REVIEW OF 3 PHASE SCR CONVERTER - DC HARMONICS	6
7.	CHARACTERIZATION OF THE LAMP'S RIPPLE	11
	7.1 Measurement of The Lamp's Ripple	11
	7.2 Fourier Analysis of the Arc's Light Intensity	15
	7.3 Measurements of the Random Fluctuations in the Arc's Light	20
8.	RIPPLE REDUCTION GOAL	31
	8.1 Requirements of Present Test Standards	31
	8.2 Achievable Ripple Reduction Goal	31
9.	METHODS FOR RIPPLE REDUCTION	32
	9.1 Increase Number of AC Phases	32
	9.2 Increase the AC Frequency	35
	9.3 Power Transistor Converter	35
	9.4 High Frequency Switching Power Supply	35
	9.5 AC-toDC Generator Set	36
	9.6 Zero order Low Pass Filter	36
	9.7 First Order Low Pass Filter	38
	9.8 Second Order Low Pass Filter	39
	9.9 Resonant Band Stop Filter	40
	9.10 Resonant Band Pass Filter	40
10.	TWO ALTERNATIVE SOLUTIONS FOR REDUCING THE HARMONICS	44
	10.1 Proposed Solution: High Frequency Switching Power Supply	44
	10.2 Alternate Solution: Dual Resonant Trap Harmonic Filter	46
11.	CONCLUSIONS	52
12.	RECOMMENDATIONS	54

APPENDIX A: DATA ON THE LAMP'S RIPPLE

APPENDIX B: RECONSTRUCTION OF LIGHT INTENSITY WAVEFORMS FROM THE FREQUENCY SPECTRUM DATA

APPENDIX C: DATA OF THE FLUCTUATIONS IN THE ARC'S LIGHT INTENSITY

APPENDIX D: DATA ON THE 11 mH INDUCTOR EXPERIMENT

LIST OF FIGURES

		Page Number
FIGURE 1:	THE ARC LAMP'S OPERATIONAL CIRCUIT DIAGRAM	7
FIGURE 2:	SIX PULSE CONVERTER'S VOLTAGE WAVEFORMS	8
FIGURE 3:	THE RIPPLE IN THE ARC'S CURRENT AND LIGHT INTENSITY	12
FIGURE 4:	THE RIPPLE IN THE ARC AND SCR VOLTAGE	14
FIGURE 5:	THE POWER FREQUENCY SPECTRUM OF THE ARC'S LIGHT INTENSITY AT 100 AMPS	16
FIGURE 6:	THE POWER FREQUENCY SPECTRUM OF THE ARC'S LIGHT INTENSITY AT 250 AMPS	17
FIGURE 7:	THE POWER FREQUENCY SPECTRUM OF THE ARC'S LIGHT INTENSITY AT 350 AMPS	18
FIGURE 8:	DISTRIBUTION OF RANDOM FLUCTUATIONS AT 100 AMPS	22
FIGURE 9:	DISTRIBUTION OF RANDOM FLUCTUATIONS AT 150 AMPS	23
FIGURE 10:	DISTRIBUTION OF RANDOM FLUCTUATIONS AT 200 AMPS	24
FIGURE 11:	DISTRIBUTION OF RANDOM FLUCTUATIONS AT 239 AMPS	25
FIGURE 12:	DISTRIBUTION OF RANDOM FLUCTUATIONS AT 300 AMPS	26
FIGURE 13:	DISTRIBUTION OF RANDOM FLUCTUATIONS AT 350 AMPS	27
FIGURE 14:	COMPARISON OF THE RIPPLE AND THE RANDOM FLUCTUATIONS	28
FIGURE 15:	A 6 PHASE DELTA PARALLEL CONNECTION	34
FIGURE 16:	ZERO ORDER LOW PASS FILTER	37
FIGURE 17:	FIRST ORDER LOW PASS FILTER	37
FIGURE 18:	SECOND ORDER LOW PASS FILTER	42
FIGURE 19:	RESONANT BAND STOP FILTER	42
FIGURE 20:	RESONANT BAND PASS FILTER	43
FIGURE 21:	HIGHER ORDER LOW PASS DAMPED FILTERS	43
FIGURE 22:	DUAL TRAP HARMONIC FILTER	47
FIGURE 23:	FREQUENCY RESPONSE OF THE DUAL TRAP HARMONIC FILTER	49

LIST OF TABLES

		Page Number
TABLE 1:	CALCULATED DC HARMONIC MAGNITUDES AT THE SCR	10
TABLE 2:	SUMMARY OF FREQUENCY SPECTRUM DATA	19
TABLE 3:	SUMMARY OF RANDOM FLUCTUATION DATA	29
TABLE 4:	SECOND ORDER FILTER CALCULATIONS	41
TABLE 5:	SUMMARY OF HARMONIC FILTER CALCULATIONS	51

1. EXECUTIVE SUMMARY

The ripple in the irradiance of an arc lamp, used as a solar simulator by the National Solar Test Facility, was examined to determine its magnitude and recommend a cost effective solution to reduce it to an acceptable level.

The 120 kW arc lamp's supply is a six pulse SCR ac-to-dc converter. The percentage of ripple in the light intensity, which is identical to the ripple in the arc's current, ranged from 90% at the minimum light intensity to 15% at the maximum light intensity. Various methods, ranging from alternate high current dc sources to different harmonic filtering schemes, were studied. A high frequency switching power supply has been identified as the best way to reduce the ripple, and the fluctuations caused by the arc's inherent instabilities, to below 1%. This can only be achieved by a low ripple power supply design (i.e. <0.5%) with a fast response time constant, that will control the magnitude of the light intensity fluctuations in the arc by means of a feedback loop.

2. RESUME

3. INTRODUCTION AND BACKGROUND

A 120 kW dc arc lamp, designed and built by Vortek Industries is being used as a solar simulator at the National Solar Test Facility (NSTF) operated by ORF for EMR.

Previous work with this solar simulator determined the existence of a 360 Hz ripple in the lamp output. For testing of solar thermal collectors, the effect of the ripple is negligible because of their long thermal response time constant. In the case of solar cells and PV panels which are essentially reverse biased diodes, the ripple in the light's intensity is seen in their current output due to the faster response of these devices.

The traditional method of measuring PV panels response, by the capacitive discharge method, cannot be used because the lamp ripple is 15% to 90% (peak-to-peak) of the average light intensity. This method, developed for flash simulators, consists of scanning the IV curve in less than 2 ms during a single Xenon arc flash. The technique currently used at the NSTF, measures the IV curve by a slow scan with multiple current readings at each voltage step to average out the ripple. The design of the measuring equipment is therefore more complex. Moreover, during the slow IV curve scan, the solar cells heat up, altering their response.

By decreasing the percent ripple in the light intensity to 1% (e.g. CSA F380 $\pm$ 1%), the NSTF's PVI capacitive discharge unit could be employed to achieve data of comparable accuracy to those obtained in facilities using Xenon flash lamp simulators. Also, the existing measuring system could be simplified to perform high speed IV curve scans, minimizing the rising cell temperature effect during the measurement.

4. OBJECTIVES

The main objective of the present program was to reduce the output ripple of the NSTF solar simulator. The tasks carried out were:

1. Characterize the arc's voltage, current and light intensity with respect to their ripple content and characterize the arc in terms of circuit elements for circuit analysis.

2. Determine the degree of correlation between the ripple in the light intensity and the ripple in the arc's current so as to predict the reduction of the ripple in the light intensity when the ripple in the current is reduced.

3. Determine the theoretical minimum ripple in the light intensity that should be attainable after determining the arc's stability.

4. Identify the various methods used in producing a low ripple content dc supply and determine their feasibility and their cost effectiveness.

5. METHOD

The arc and SCR voltages and the arc's current and light intensity were measured at six arc current levels covering the entire usable output range of the arc lamp. From this data, the ripple content and the arc's electrical characteristics were obtained. Fourier analysis was also performed on the light intensity. In order to evaluate the data obtained on the lamp output, a brief review of a three phase SCR ac to dc converter is presented.

The various methods to reduce the ripple in a dc supply or producing a low ripple content dc supply were reviewed and a cost effective solution was found. A recommended and alternative solution are discussed in more detail as to their effectiveness.

6. REVIEW OF 3 PHASE SCR CONVERTER - DC HARMONICS

In Figure 1, the operational schematic diagram of the arc lamp's dc circuit is given. The SCR converter is a three phase bridge converter often referred to as a six-pulse converter. For a six-pulse converter, the frequencies of the harmonics on the dc side are given by

$$n^{th} \text{ harmonic} : \quad n = 2pK \qquad \{p = \text{number of phases} = 3\} \qquad (1)$$

$$\{k = 1,2,3.....\}$$

$$\text{frequency:} \qquad f = n60(hz) \qquad (2)$$

The maximum average rectified voltage for a six pulse converter is

$$V_{dc\ max} = 3\sqrt{2}/\pi \ \ V_{phase\text{-}phase} \qquad (3)$$

$$= 1.35 \times 240V = 324\ Vdc$$

The dc voltage waveform is illustrated in Figure 2 [1]. The firing angle delay α controls the dc voltage and current. The commutation angle delay μ is the time required for transferring from one pair of SCR's to the next and is essentially determined by the reactive impedance of the ac source (i.e. transformer). The rms magnitudes of the harmonic voltages on the dc side of the converter have been derived by J. Arillaga, et.al [1] and is given by:

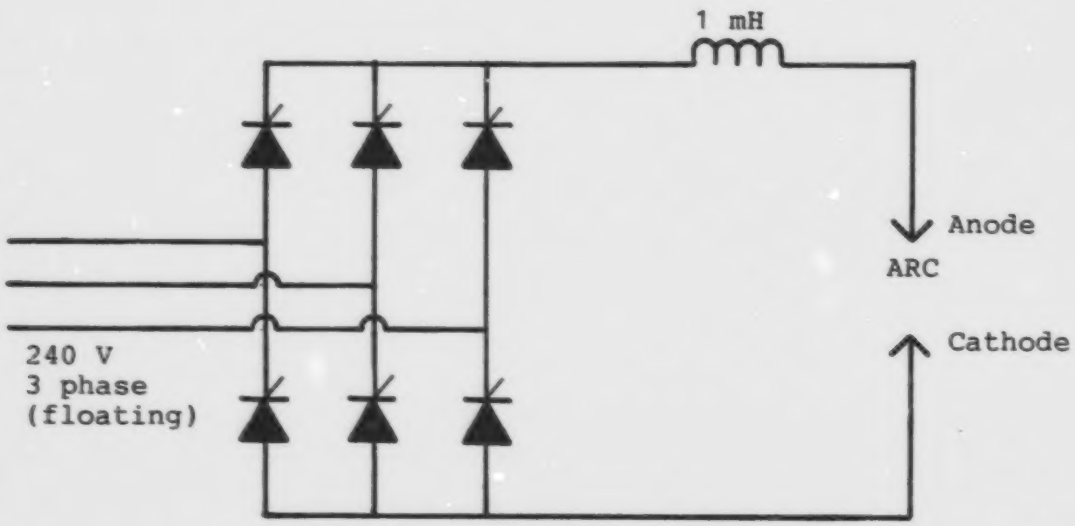


Figure 1. The arc lamp's operational ciruit diagram.

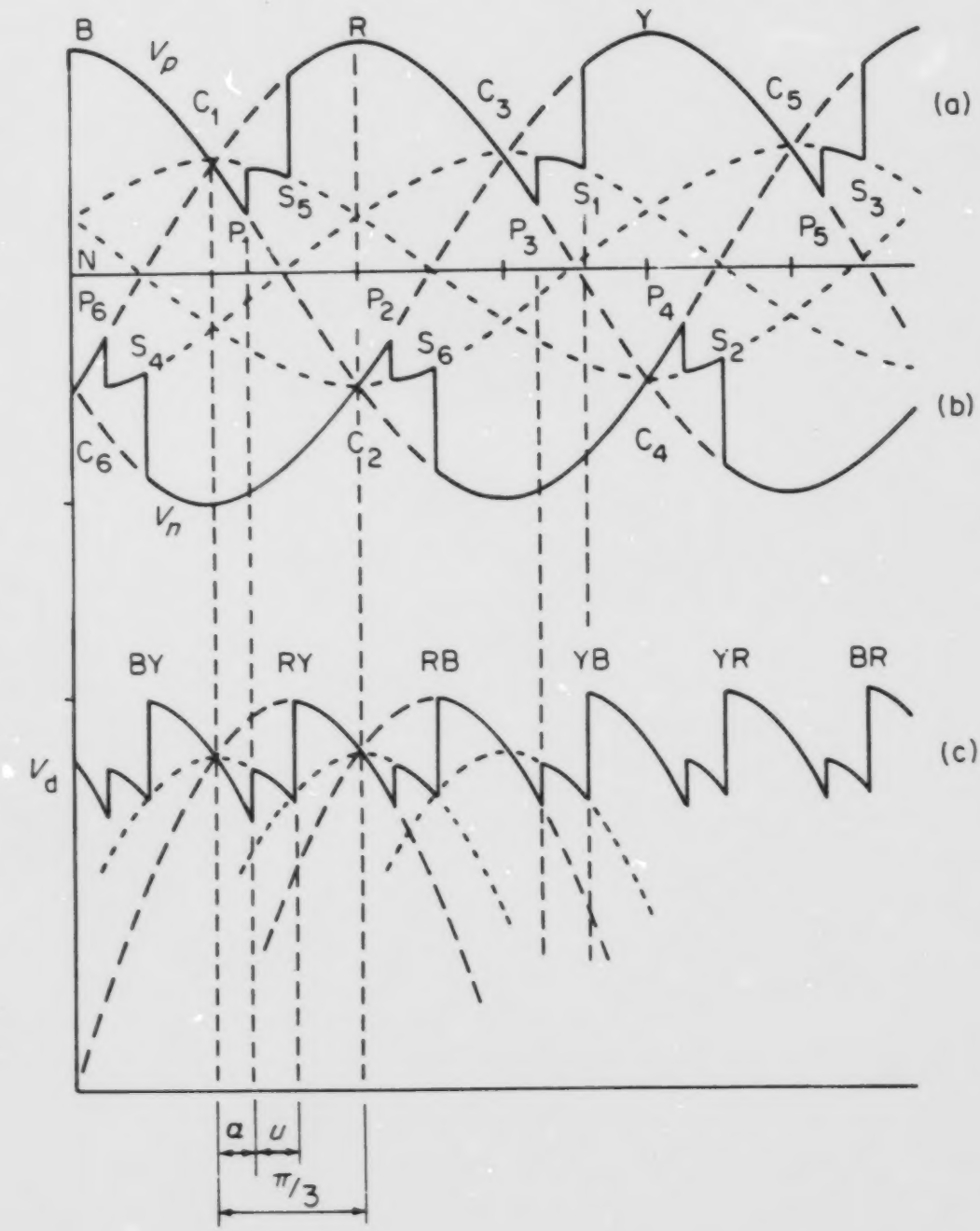


Figure 2 Six-pulse converter's voltage waveforms: [1]

a) at the positive terminal (Vp)
b) at the negative terminal (Vn)
c) dc output (Vd)

N.B. during the commutation delay stage after SCR has been turned on at ∝, the output voltage follows the common anode voltage.

$$Vn = \frac{Vdc_{max}}{\sqrt{2}(n^2-1)} \{ (n-1)^2\cos^2 [(n+1)\mu/2] + (n+1)^2 \cos^2[(n-1)\mu/2] - 2(n-1)(n+1)\cos [(n+1)\mu/2]\cos [(n-1)\mu/2]\cos(2\alpha+\mu)\}^{1/2} \quad (4)$$

As the commutation angle for the arc lamp is negligible, equation (4) becomes

$$Vn = \frac{Vdc_{max}}{\sqrt{2}(n^2-1)} \{(n-1)^2 + (n+1)^2 - 2(n-1)(n+1)\cos(2\alpha)\}^{1/2} \quad (5)$$

The peak-to-peak magnitudes of the no-load voltage harmonics across the SCR's are presented in Table 1 for firing angle delays α of 30^o and 5^o which correspond to an arc current of approximately 100A and 350A respectively (-20A, +40A). The waveform can be reconstructed by using

$$v = \sum_n \sqrt{2}\, Vn \cos (n\, wt + \theta_n) \quad (6)$$

where θ_n is the phase shift of each harmonic.

The actual peak-to-peak magnitude will be lower due to the phase relations of the harmonics.

Table 1: Calculated DC Harmonic Magnitudes at the SCR

V	k	n	f(HZ)	Vn(peak-peak)(V)
30^{o}	1	6	360	115.6
	2	12	720	54.9
	3	18	1080	36.3
	4	24	1440	27.1
	5	30	1800	21.7
	6	36	2160	18.0
5^{o}	1	6	360	41.7
	2	12	720	13.1
	3	18	1080	7.5
	4	24	1440	5.2
	5	30	1800	4.0
	6	36	2160	3.3

7. CHARACTERIZATION OF THE LAMP'S RIPPLE

The measurements and analysis of the lamp's ripple concentrated on three areas, namely, the magnitude, the frequency spectrum and the noise.

7.1 Measurement of the Lamp's Ripple

7.1.1 Test Procedure and Results

The lamp output intensity, the arc voltage, the SCR voltage and the arc current were measured over the lamp's operating range of 100A to 350A dc. The waveforms were obtained by a Tektronix 2430 digital oscilloscope and directly plotted on a HP Think Jet printer. The noise on the signal was reduced by 20.5 dB by obtaining a composite waveform produced from averaging 128 waveforms. If this averaging method had not been used, the data would have been obscured by the noise and fluctuations, as seen in Section 7.3.

7.1.1.1 Light Intensity

The waveforms for the light intensity are given in Appendix A.1 where the output of a Silonex Cell NSL-792 with a 0.875 Ω load resistance was compared to the output of a calibrated reference cell with a 26.52Ω load resistance. The ripple content was defined as the peak-to-peak voltage divided by the average voltage and given as a percentage. The average voltage was obtained by measuring the difference of the ac-ground and dc-ground with respect to the bottom peaks of the waveform in both the ac- and dc-coupled modes. The data is summarized in Figure 3 in terms of the percent ripple as a function of arc current. Measurements from reference [2] are also included for comparison.

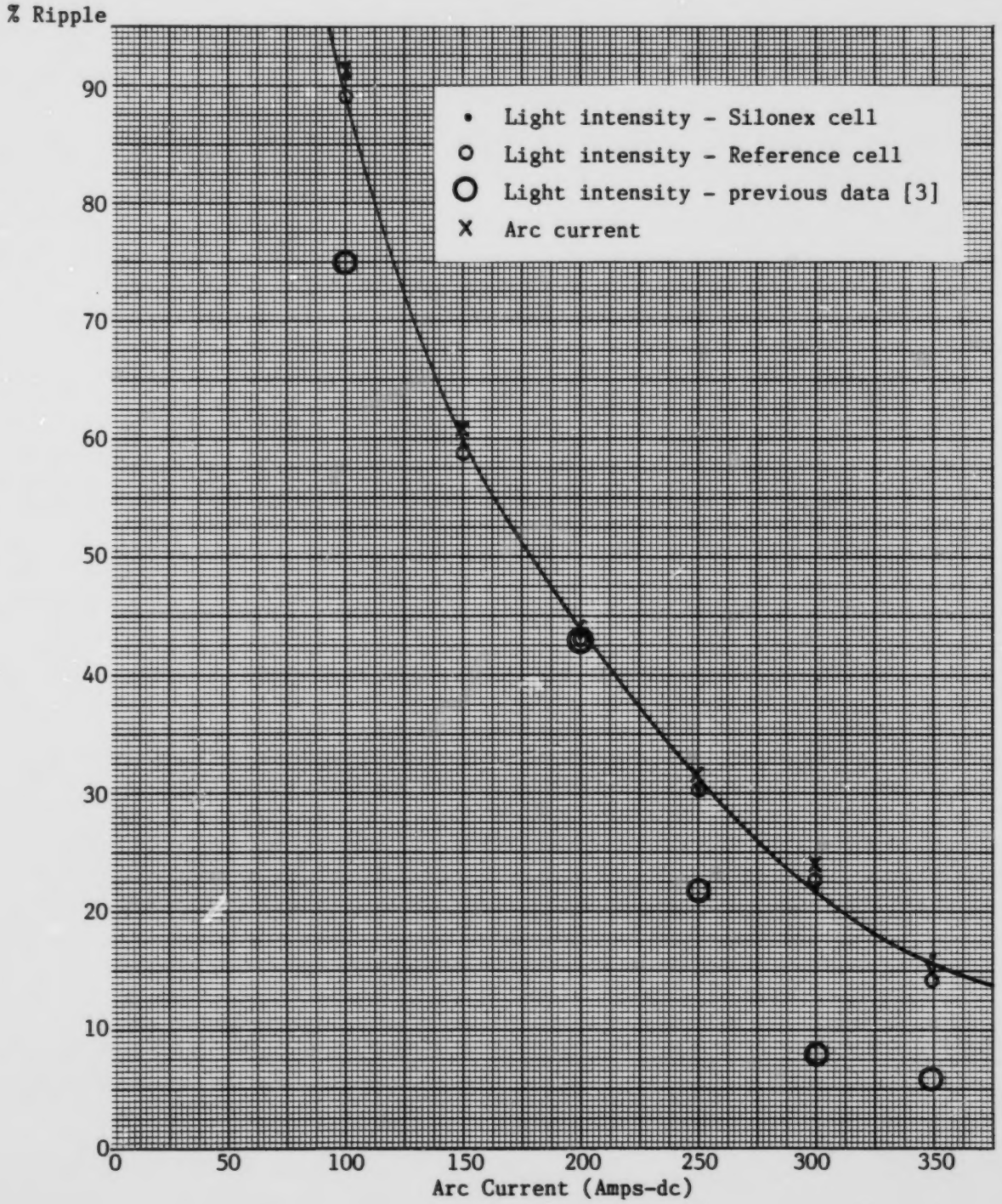


Figure 3. The ripple in the arc's current and light intensity.

7.1.1.2 Arc Current

The waveforms for the arc current are given in Appendix A.2. The waveforms were obtained from the output of a transformer-coupled isolation amplifier. This supplies the control circuitry with the corresponding floating voltage across a current measuring shunt in the main SCR operational circuit. By plotting the percent current ripple as a function of current in Figure 3, it can be observed that it is slightly higher than the light intensity ripple. By comparing the light and current waveforms, the current waveform has a much higher high frequency content. Some of the high frequency components in the current may be attributable to the floating isolation amplifier and high frequency ground noise, because the discontinuities in the current waveform cannot exist with an inductance of 1mH in the circuit.

7.1.1.3 SCR Voltage and Arc Voltage

The voltage waveforms of the SCR and the arc are given in Appendix A.3 and A.4 respectively. As the arc's current waveforms and the arc's voltage waveforms have the same general shape, the purely resistive nature of the arc is confirmed. The percent ripple data for the SCR and arc voltages are plotted in Figure 4.

7.1.2 Remarks on the Ripple Data

As the average light intensity is directly proportional to the average arc current, and the percent ripple in the light intensity is equal to the percent ripple in the arc current, any results of ripple content analysis on the arc current also directly applies to the light intensity ripple content.

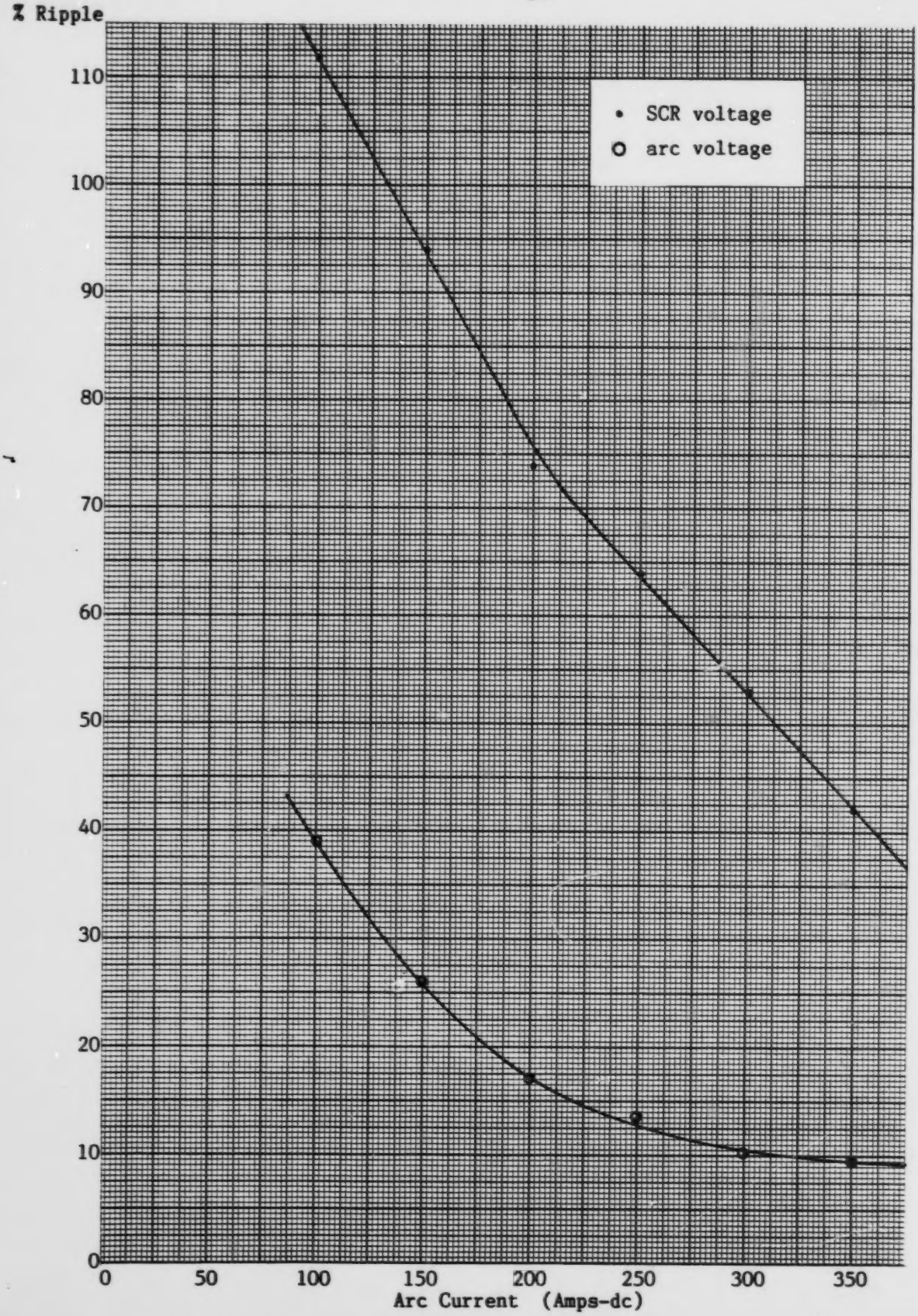


Figure 4. The ripple in the arc and SCR voltages.

7.2 Fourier Analysis of the Arc's Light Intensity

Fourier analysis was performed in order to simulate the effects that various filtering designs would have on reducing the magnitude of the ripple.

7.2.1 Test Procedure and Results

A 12 bit Genrad Digital Signal Processing Computer was used to obtain the power spectrum of the ac coupled (8Hz cutoff; 20xgain) signal from a Silonex 792 cell, terminated with a 10Ω resistor. A Hanning window was used to reduce the errors introduced in the frequency spectrum by the edges of the sample window as the sampling period was not a multiple of 60 Hz. The amplitude correction factor is 1.535 which is close to the theoretical correction factor of $\sqrt{8}/3$. The frequency spectrum for 100A, 250A and 350A are given in Figures 5 to 7 respectively with the data summarized in Table 2. In Appendix B, the light intensity waveforms are reconstructed from this data for use in later sections of this report.

7.2.2 Discussion on Fourier Analysis Data

For a three-phase, six-pulse converter, according to equation (2), the lowest harmonic frequency is 360 Hz with high frequencies being multiples of 360 Hz. As the SCR's are not currently fired by a phase-lock-loop circuit, lower harmonics that are multiples of 60 Hz appear. Replacing the original timing circuit, with any commonly available phase-lock-loop timing circuit will reduce these frequency components (i.e. 120, 240, 480, 600 Hz) by at least 95%, resulting in only a 5 to 10%

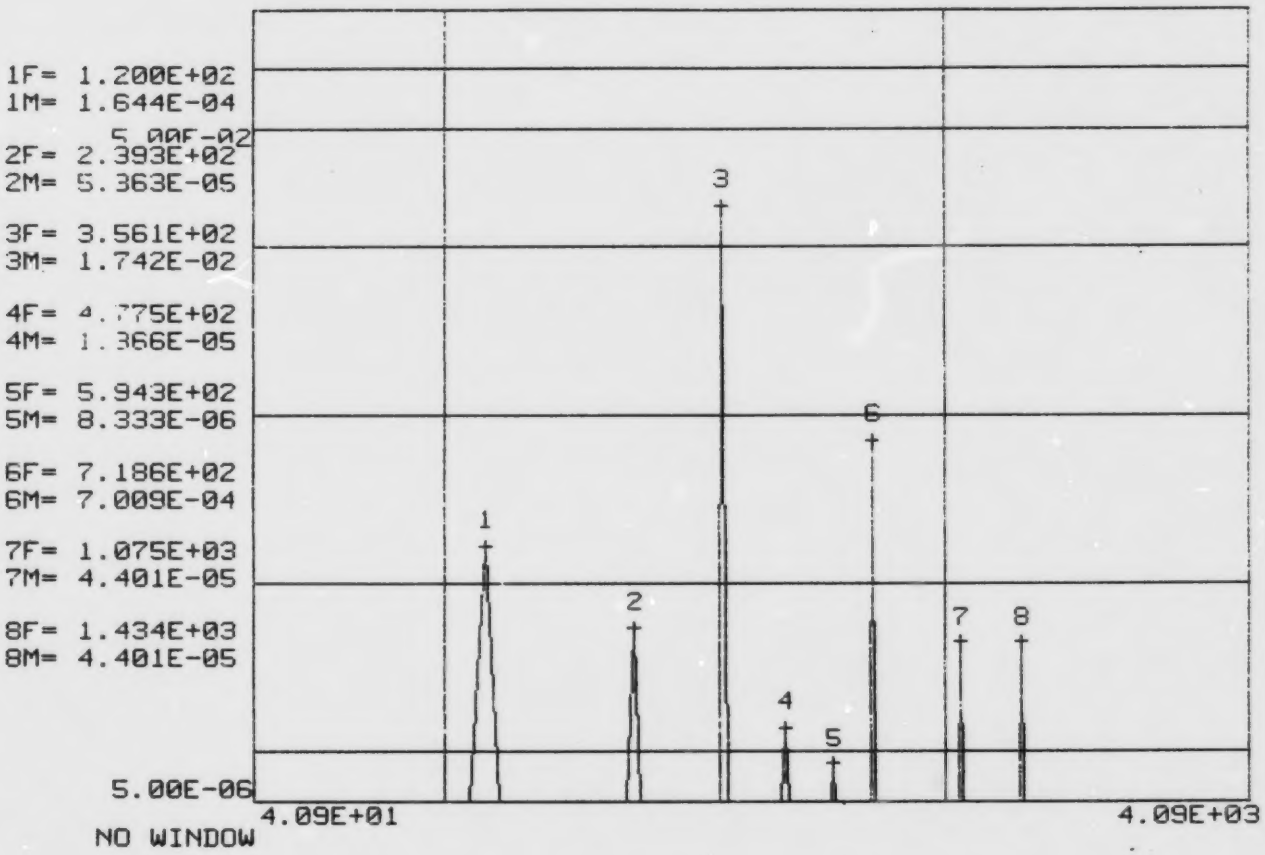


Figure 5. The power frequency spectrum of the arc's light intensity at 100 Amps.
N.B. F - frequency
M - amplitude without Hanning Window

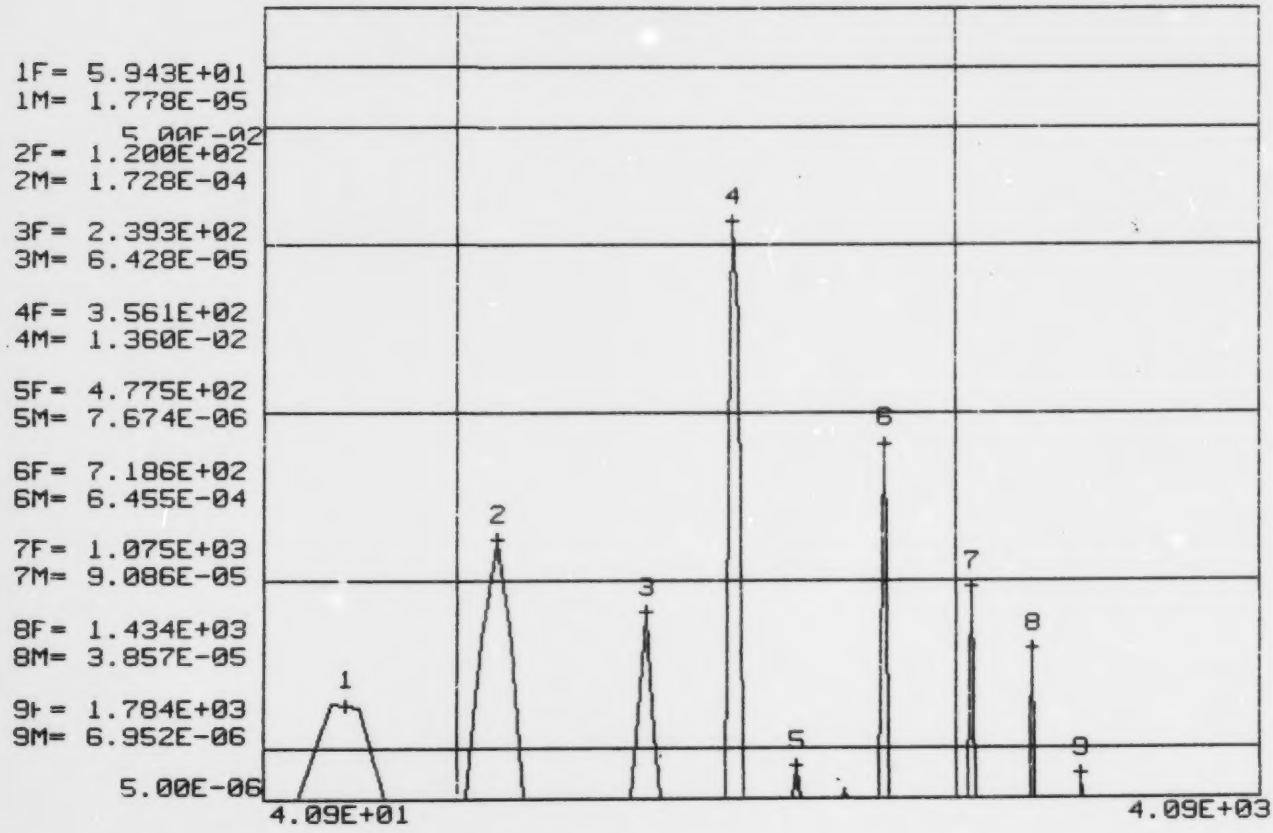


Figure 6. The power frequency spectrum of the arc's light intensity at 250 Amps.

N.B. F - frequency
M - amplitude with Hanning Window

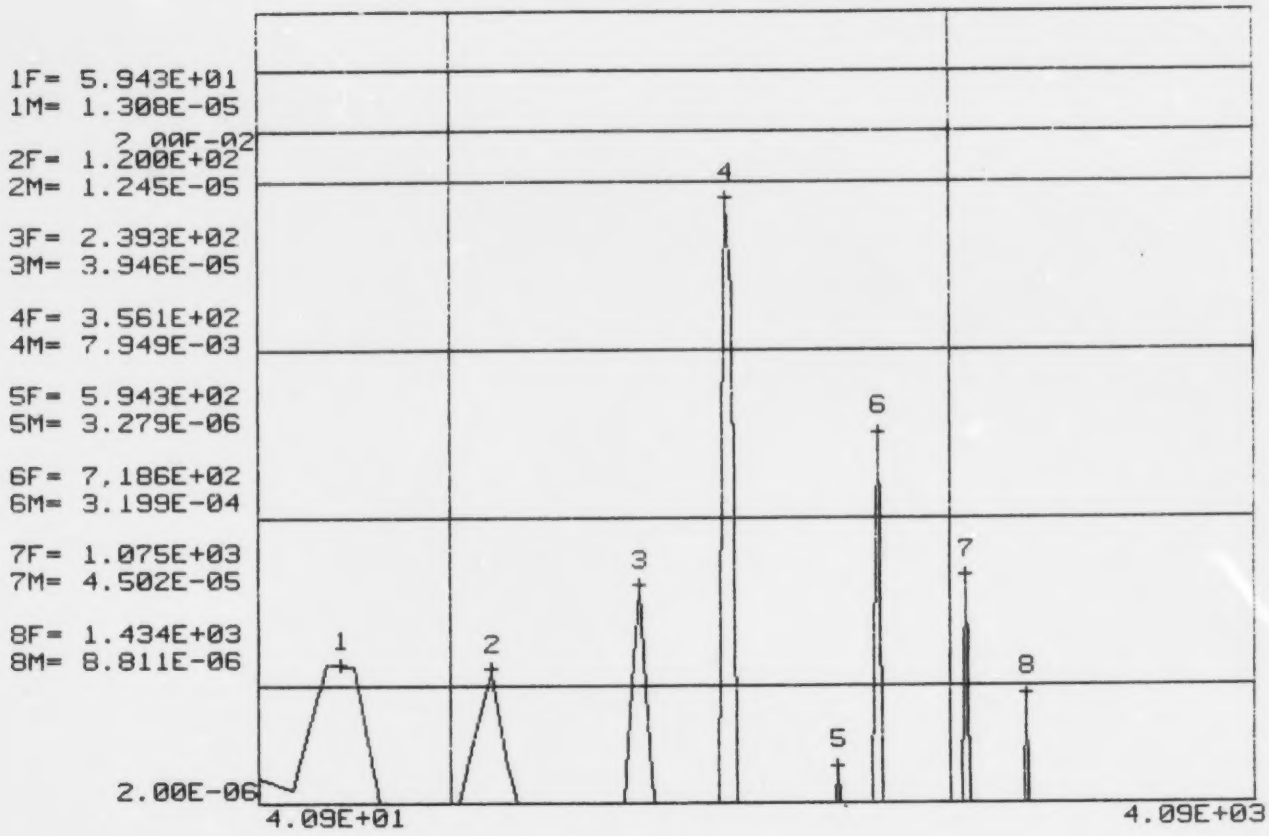


Figure 7. The power frequency spectrum of the arc's light intensity at 350 Amps.

N.B. F - frequency
M - amplitude with Hanning Window

Table 2: Summary of Frequency Spectrum Data

Arc Current Irradiance Figure #	100A ~250 W/m^2 Fig. 5	250A ~700 W/m^2 Fig. 6**	350A ~1000 W/m^2 Fig. 7**
Frequency (Hz)	(mV)*	(mV)*	(mV)*
60		10.4	9.0
120	25.6	32.6	8.7
240	14.6	19.9	15.6
360	264.0	289.0	220.9
480	7.4	6.9	
600	5.8		4.5
720	52.9	63.0	44.3
1080	13.3	23.6	16.6
1440	13.3	15.4	7.4
1800		6.5	

Notes * Amplitude = (power amplitude *4)^{½}
** Power amplitude corrected for the Hanning Window factor of 1.535

reduction in the ripple as shown in Appendix B. If a harmonic filter is to be implemented, the use of a phase-lock-loop timing circuit will simplify the design.

7.3 Measurements of the Random Fluctuations in the Arc's Light Intensity

By determining the magnitude and possible causes of the random fluctuations in the arc's light intensity the lowest achievable maximum ripple can be estimated.

7.3.1 Test Procedure and Results

The method used in determining the accumulative noise and fluctuations in the measured signal was by operating the Tektronix 2430 digital oscilloscope in its envelope mode. This mode produced an upper and lower curve between which all 256 waveforms occurred. The oscilloscope was controlled by a dedicated process controller (PC) which retrieved the resultant data from the oscilloscope, for later analysis and plotting by a personal computer (PC).

The light intensity was measured on a 90^{o} target plane which was at a distance of 13 m from the arc. A Silonex 792 cell with a 10Ω load resistance and 50Ω termination to the coax cable and foil shielding was used to measure the light intensity. The 50Ω termination was chosen because it resulted in the minimum peak-to-peak noise (i.e. less than 0.4 mV - Figures C127, C128) relative to the average light intensity levels measured.

The light intensity was measured in the top two quadrants of the target plane, ranging from 144.7 cm to the left of the centre, to 116.8 cm to the right of the centre at a height of 45.7 cm above the centre. The results are given in Appendix C in Figures C1 to C126. The distribution of the random fluctuations versus target plane position is summarized in Figures 8 to 13. (N.B. arc's anode is to the left of the arc's centre and the cathode to the right). The random fluctuations versus arc current are compared to the ripple in Figure 14 and Table 3. Also, similar measurements were taken of the arc's voltage and current and are given in Figures C109 to C120 and Figures C121 to C126 respectively.

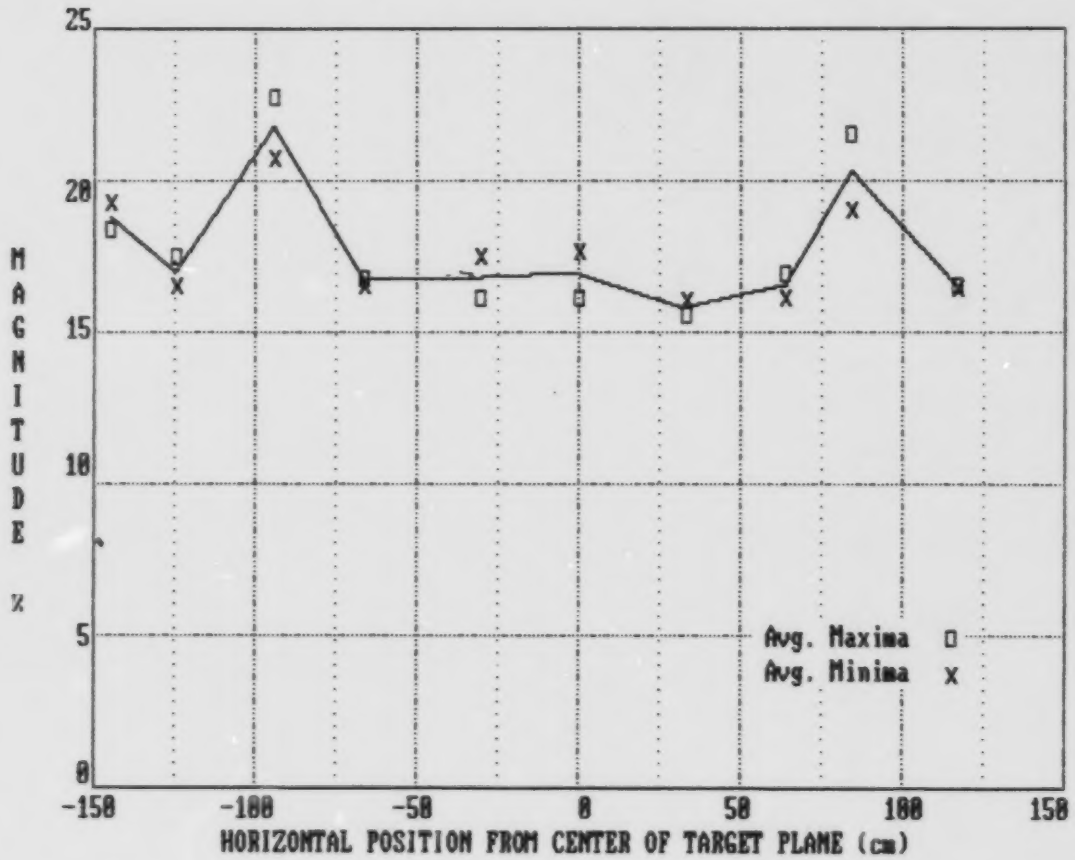


Figure 8. Distribution of random fluctuations at 100 Amps.

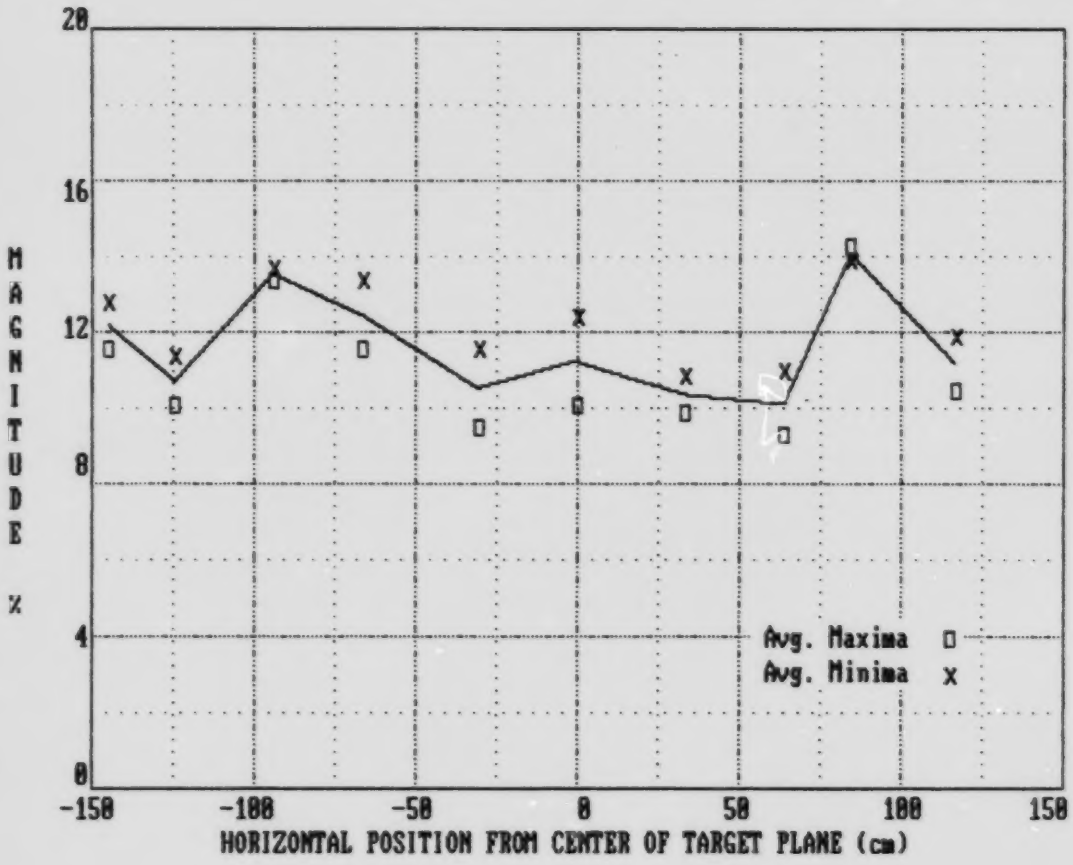


Figure 9. Distribution of random fluctuations at 150 Amps.

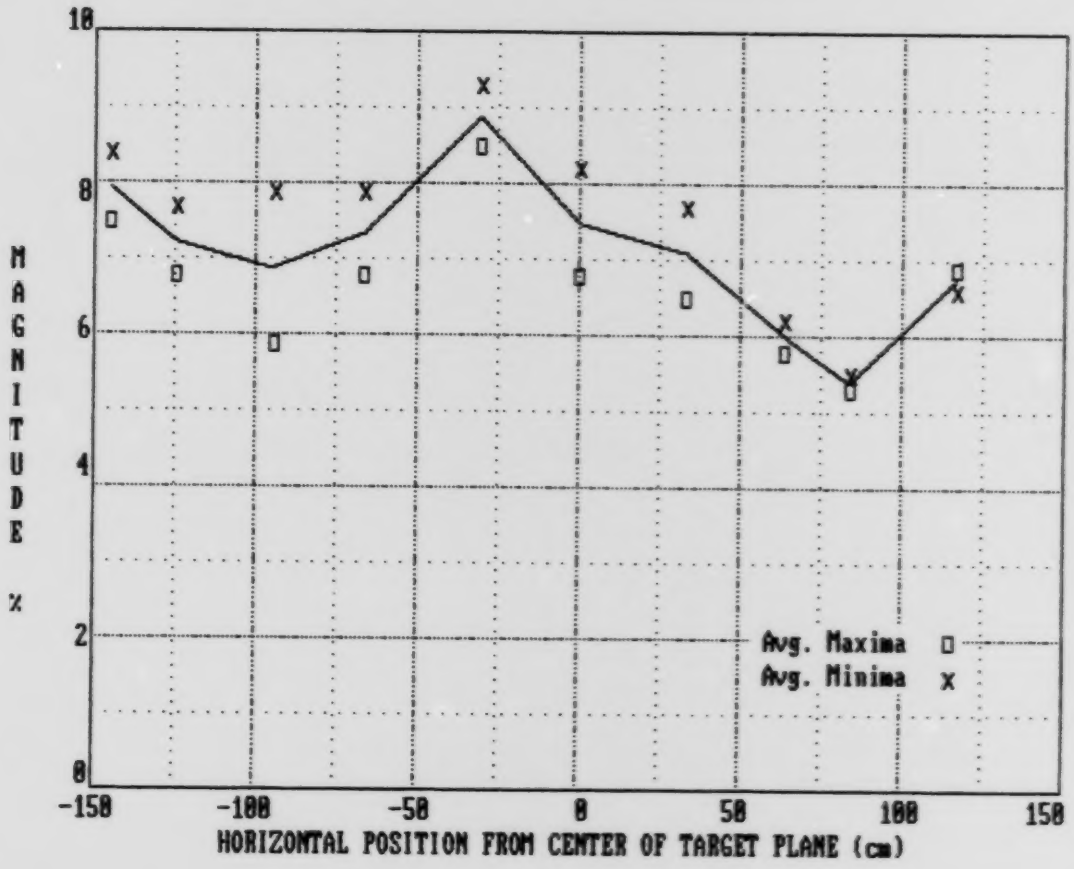


Figure 10. Distribution of random fluctuations at 200 Amps.

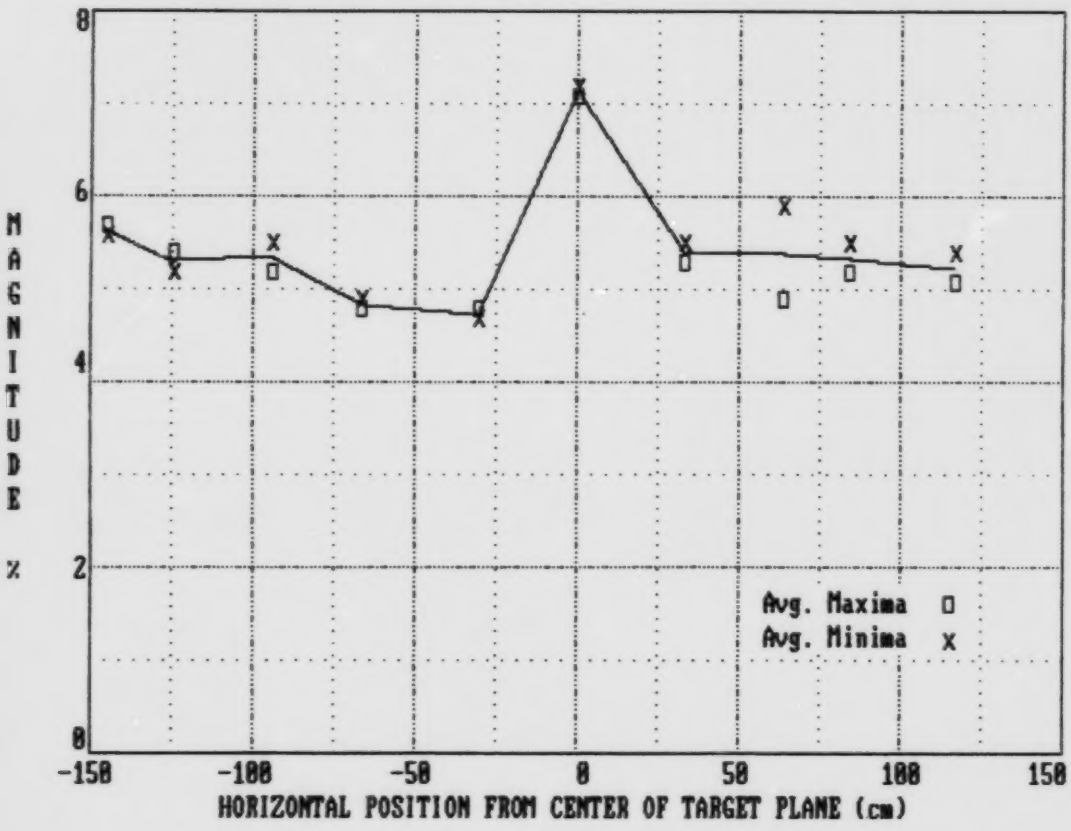


Figure 11. Distribution of random fluctuations at 239 Amps.

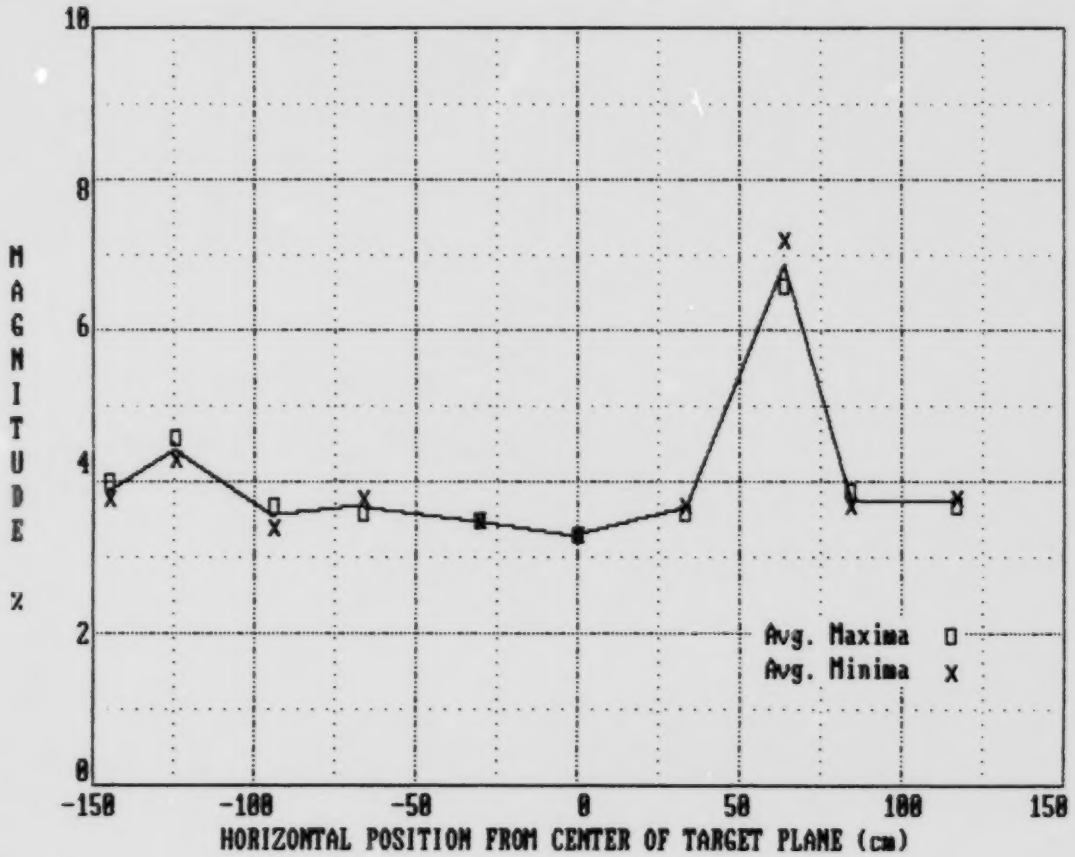


Figure 12. Distribution of random fluctuations at 300 Amps.

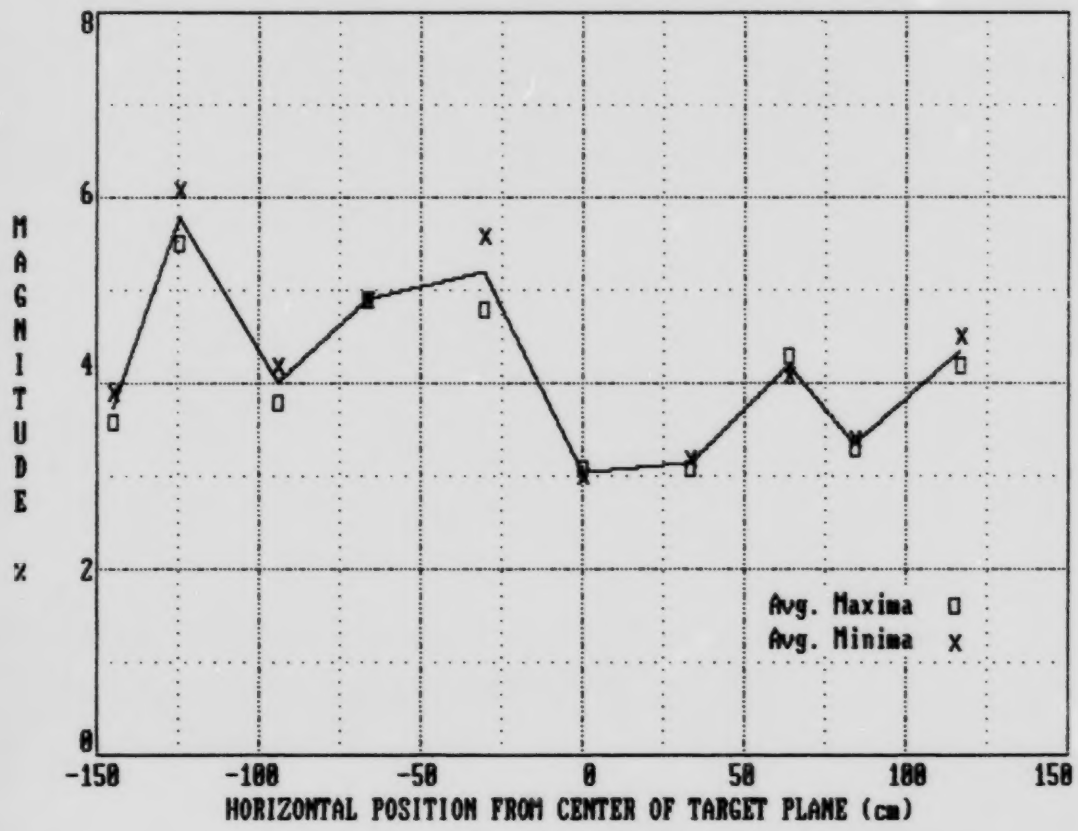


Figure 13. Distribution of random fluctuations at 350 Amps.

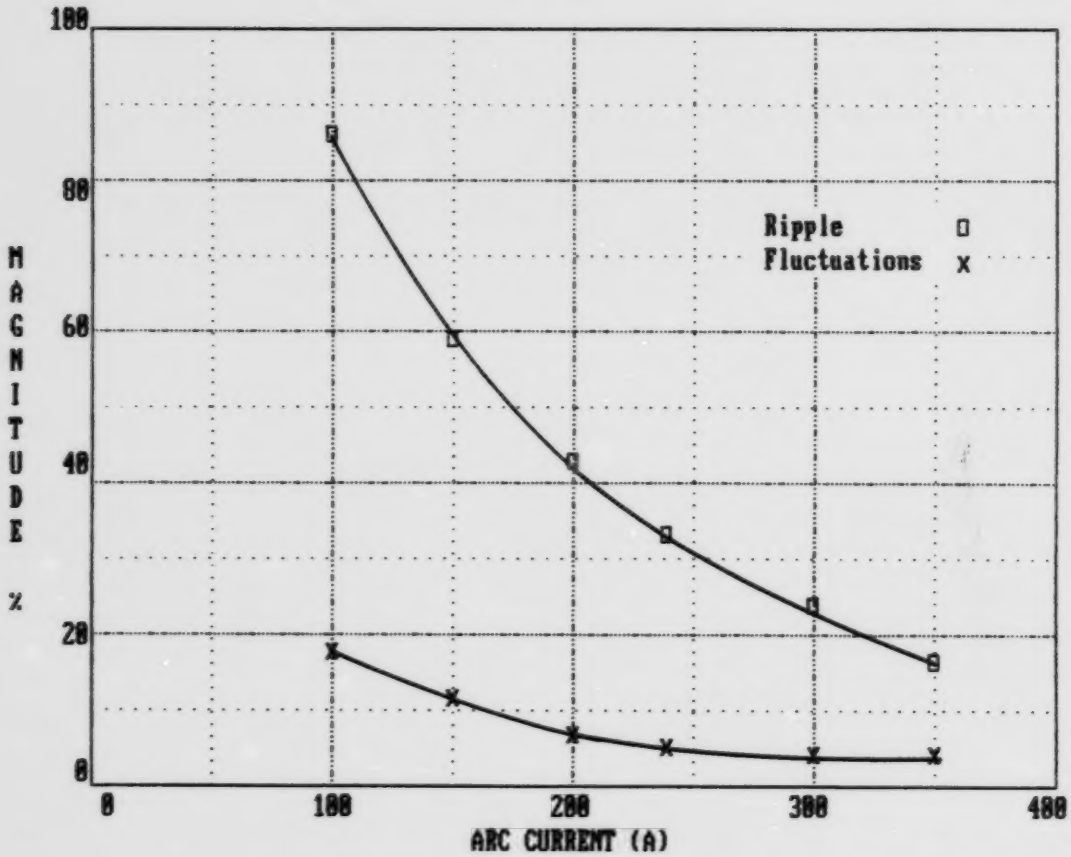


Figure 14. Comparison of the ripple and the random fluctuations.

Table 3: Summary of Random Fluctuation Data

Arc Current (Amp)	Ripple (%)		Noise at the Maxima (%)		Noise at the Minima (%)	
	Avg.	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.
100	86.2	1.21	18.1	2.13	17.7	1.53
150	59.1	0.61	11.0	1.30	12.3	1.01
200	43.2	1.83	6.5	0.84	7.4	1.30
239	33.1	0.53	5.4	0.54	5.5	0.50
300	24.2	0.33	4.4	1.13	4.3	1.15
350	16.5	0.32	4.4	1.23	4.6	1.45

7.3.2 Remarks on Random Fluctuation Data

There are two main sources for the random fluctuations, i.e. they are the wandering of the cathode spot and the perturbations in the gas vortex and water wall. When the cathode spot wanders, a noticeable decrease in intensity occurs as seen in Figures C15, C72, C84, C87 and C107. This phenomenon is dependent on the sharpness of the cathode's point and can occur as frequently as every 3 to 5 minutes and last for a duration of approximately 2 to 4 360 Hz cycles. The perturbation in the gas vortex and the water wall result in a random fluctuation in intensity whereby the intensity of several cycles increase or decrease simultaneously. These fluctuations are continuous and are primarily responsible for the measured random noise.

8. RIPPLE REDUCTION GOAL

8.1. Requirements of Present Test Standards

The maximum insolation error allowed in C.S.A. "Photovoltaic Modules" pF380 is ± 1% at 1000 W/m^2 which corresponds to an arc current of approximately 300A. The typical error in a capacitive discharge IV scanning unit (e.g. P.V.I.) is ± 1% [3]. The typical current range for the majority of PV performance tests is 250A to 350A which correspond to a 30% - 15% ripple. There also exist test standards that require a wider range of insolation level (e.g. Canadian Coast Guard) which extends into the 100A range (90% ripple). If the ripple in the arc's light intensity was reduced to below 1%, the commonly used capacitive discharge scanning method could be used to determine PV module performance.

8.2 Achievable Ripple Reduction Goal

Ideally, a maximum ripple of 1% is required, but due to the random fluctuations this is not achievable by either filtering the ripple to below 1% or replacing the existing power supply with a low ripple power supply (i.e. ½%). By reducing the power supply ripple below 1%, the random fluctuations will only be reduced to 5%. As the fluctuations are a slow phenomenon, increasing the 3 dB cut off frequency of the photodiode sensor from 0.07 Hz to as high as 500 Hz to 1 kHz may achieve a total noise and ripple requirement of 1%. This is only feasible in a power supply that has no harmonics below 10 kHz. Therefore, assuming such a power supply is available, maximum ripple over its full operating range will have to be less than ½%.

9. METHODS FOR RIPPLE REDUCTION

The methods for ripple reduction in a dc supply fall into two general categories, as follows:

(1) At the ac-to-dc conversion stage:
- increase the number of ac phases
- increase the ac frequency
- power transistor converter
- high frequency switching power supply
- ac-to-dc generator set

(2) Beyond the ac-to-dc conversion stage:

- linear low pass filter	- series inductor or shunt capacitor
- 1st order low pass filter	- series resistor & shunt capacitor
- 2nd order low pass filter	- series inductor & shunt capacitor
- band stop filter	- series resonant trap
- band path filter	- shunt resonant trap

All ripple reduction schemes incorporate one or more of the filtering alternatives as no electronic ac-to-dc conversion process is ripple free. The various methods are discussed briefly in the following subsections. A detailed analysis and discussion of the alternate solutions is given in Chapter 10.

9.1 Increase Number of AC Phases

Increasing the number of phases to 6 (12,18,24,30,36,48) will decrease the number of dc side harmonics by a factor of two and the number of ac side harmonics by a factor of four. The main

benefits of increasing the number of phases is the higher frequency of the first harmonic which results in a significant reduction in filtering costs.

Other benefits are the reduction of the magnitude of the ripple (e.g. 6 phase: ~2 to 3.5 times) and the reduced SCR current handling requirements. In practice, the cancelled harmonics are only reduced by a maximum of 95% [4].

The most economical method of achieving 6 phases is by incorporating a second transformer to obtain a matching Wye-Delta and Delta-Delta pair. Due to the low voltage and high current requirements, the two sets of 6 SCR's should be connected in parallel as shown in Figure 15. The arc lamp utilizes the transient response of its floating SCR source during the complex starting sequence. This configuration will probably have the least effect on the supply's transient response in comparison to other possible six phase configurations.

At the design stage, a six phase SCR converter with harmonic filtering is probably the most cost effective method in reducing the harmonics. Converting the existing 3 phase SCR converter to 6 phase will require a total re-design and a new set of 12 SCR's and SCR control circuitry. The difference in costs of the filter components for a 6 phase converter in comparison with a 3 phase converter is negligible compared to the total costs of changing to a 6 phase converter for this application.

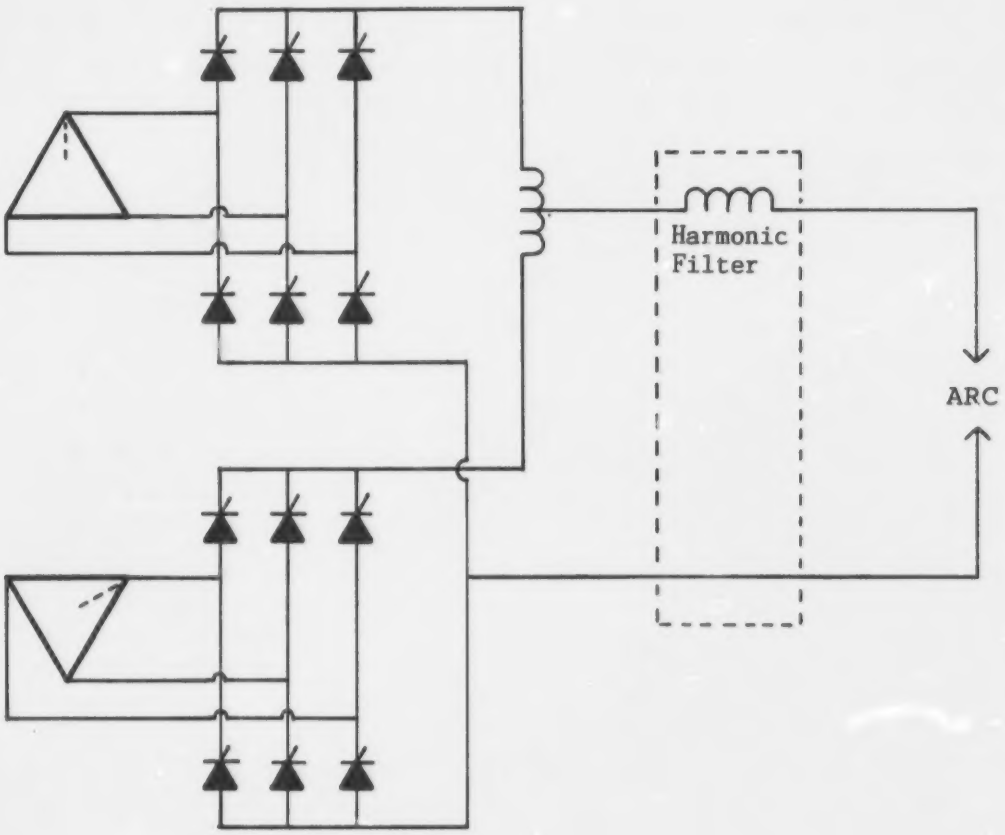


Figure 15. A 6 phase delta parallel connection.

9.2 Increase the AC Frequency

By increasing the ac frequency, the frequency of the lowest harmonic will increase proportionally, resulting in decreased filter component costs. The maximum frequency is limited by the SCR turn on and off time delays (i.e. commutation) and the degree of voltage or current control required. The common frequency of 400 Hz is near the limit for 3 phase SCR response. In addition, the cost of a high frequency source such as an ac motor-generator set, is too high.

9.3 Power Transistor Converter

Due to the high current requirements, replacement of SCR's with power transistors will not be economically feasible despite recent progress in power transistor technology.

9.4 High Frequency Switching Power Supply

A high frequency switching power supply first converts the ac to dc by means of rectifiers and then chops the dc with switching power transistors or high frequency SCR's into a high frequency square wave. The high frequency ac is transformed to the required voltage level where it is converted to dc by rectifiers. The output current and voltage are determined by the intermediate dc voltage and the conduction time period of the power transistor or SCR chopper circuit. The major benefit of this alternative over all other types of electronic converters is the extremely low ripple content, which is confined to the very high frequency range. These frequencies can be filtered usually with only a small ferrite core inductor in series.

For the arc lamp, the dc-to-dc conversion section can be incorporated into the existing system but the design cost would probably exceed the cost of buying an integrated supply. Due to the power requirements, an SCR chopper circuit is better from an economical and reliabilty viewpoint. As this is one of the proposed methods for reducing the ripple, it will be discussed in more detail in the following chapter.

9.5 AC-to-DC Generator Set

Due to the varying source impedance of the dc generator as the rotor turns, a very large inductance is required to prevent the arc from being excited into resonance.

9.6. Zero Order Low Pass Filter

The arc lamp requires a constant current source due to the dynamics of the arc. A capacitor in shunt (Figure 16 A) limits voltage excursions while acting as an instantaneous current source. An inductor in series (Figure 16 B) limits the current excursions. The frequency response of a zero order filter is given in Figure 16 C. In order to eliminate the ripple, very large component values are required.

The simplest filter for the arc lamp is an inductor. The ratio of the arc current to input voltage is given by:

$$\left| \frac{I_{Ra}}{V_s} \right| = \frac{1}{\sqrt{Ra^2 + \omega^2 L^2}} \qquad (7)$$

where Ra (0.33Ω) is the arc's dynamic resistance (Figure 16 D).

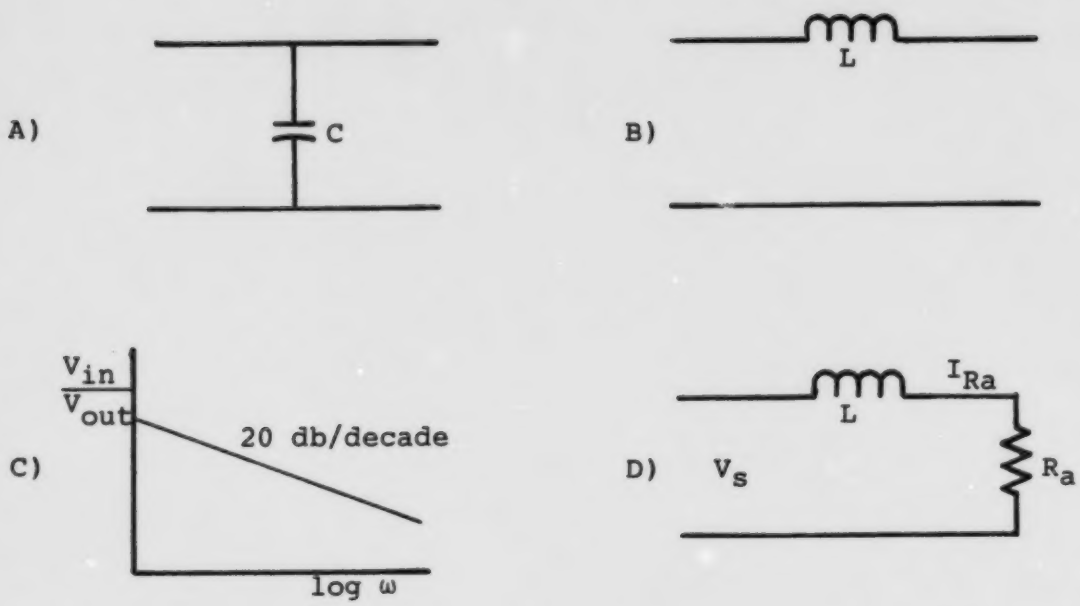


Figure 16. Zero order low pass filter.

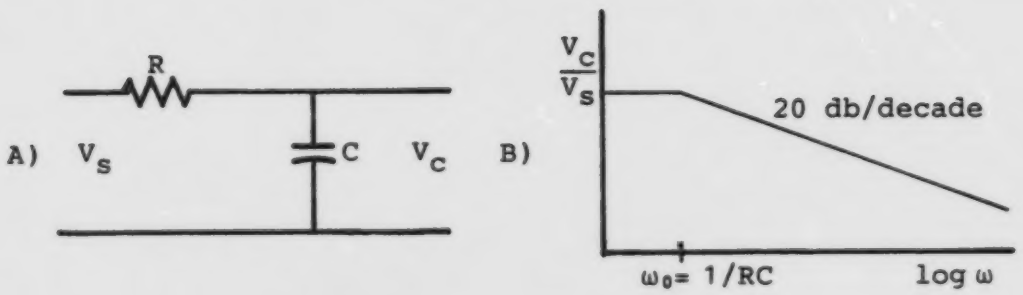


Figure 17. First order low pass filter.

This method was the original solution to be examined in this project where 10 mH inductor would be added in series to the existing 1 mH inductor. This would reduce the ripple by a factor of 10.9 at 360 Hz and 11.0 at 3600 Hz. In practice, the harmonic reduction factor will be slightly lower since the inductance decreases with frequency due to the iron core. The main concern about adding such a high impedance in series with the source, was the question of whether the ignition of the arc would be affected as there seemed to be an impedance threshold above which the arc would not proceed through its start-up procedure. As an experiment, two 5 mH, 50A inductors were added in series. The arc successfully went through its start-up procedure a number of times using partially used electrodes. The results on the harmonic content and random fluctuations are given in Appendix D at 100 amps where the equivalent ripple reduction factor was only 3.3 which corresponds theoretically to a 2.5 mH inductor (+ .042 Ω) added in series to the 1 mH (350A) inductor. This probably was the total inductance of the two 5 mH (50A) inductors in series due to saturation occurring at 100A. Therefore a 10 mH (350A) inductor would reduce the ripple at 100A to ~8.6% and the random fluctuations to ~5%.

9.7. First Order Low Pass Filter

A first order filter and its frequency response are shown in Figures 17 A and 17 B respectively. Due to the arc instabilities, a capacitor in parallel with the arc is not advisable. Also the losses in the resistor are unacceptable for high current applications such as the arc lamp.

9.8 Second Order Low Pass Filter

A second order filter and its frequency response are shown in Figures 18 A and 18 B respectively. For most dc high current applications and dc power systems, this method is the most cost effective. The losses are minimal since the damping resistance is often just equal to the inherent losses of the inductor. The frequency is given by:

$$\left| \frac{V_c}{V_s} \right| = \frac{1}{\sqrt{(1-\omega^2 LC)^2 + \omega^2 R^2 C^2}} \tag{8}$$

and the corner frequency by:

$$\omega_o = \frac{1}{\sqrt{LC}} \sqrt{1 - \frac{R^2 C}{2L}} \tag{9}$$

which simplifies to:

$$\omega_o = \frac{1}{\sqrt{LC}} \tag{10}$$

when R is small. This method is only feasible if an additional relatively large inductor is added in series with the arc to limit the capacitive currents. By evaluating the following equation for the circuit shown in Figure 18 C,

$$\frac{I_{R_a}}{V_s} = \frac{1}{R_a(1-\omega^2 CL_1) + j(\omega L_1 + \omega L_2 - \omega^3 CL_1 L_2)} \tag{11}$$

we obtain the following results shown in Table 4. To obtain a 20 times reduction factor for the 360 Hz harmonic, either the capacitor or the inductor or both will have to be increased by a factor of 2 to 3 as compared to the values in the right hand column. Increasing the size of the capacitors or inductors beyond those in Table 4 could result in very large and costly components.

9.9 Resonant Band Stop Filter

A resonant band stop filter, shown in Figure 19, is the most common method used in low cost uninterruptible power supplies. However, the high harmonic currents of the arc lamp will cause exceedingly high 360 Hz and 720 Hz voltages across the SCR's and therefore is not acceptable.

9.10 Resonant Band Pass Filter

A common method for harmonic elimination in ac power is a combination of tuned band pass filters (Figure 20 A) with a damped higher order low pass filter (Figure 21) [5,6]. The frequency response of a resonant band pass filter is given in Figure 20 B. The following equations describe the relevant properties:

Resonant frequency

$$\omega_o = \frac{1}{\sqrt{LC}} \tag{12}$$

Q

$$Q = \frac{\omega L}{R} = \frac{1}{\sqrt{R}}\sqrt{\frac{L}{C}} \tag{13}$$

Bandwidth

$$B_\omega = \frac{f_o}{Q} \tag{14}$$

Table 4: Second Order Filter Calculations

	$\left\lvert \frac{I_{Ra}}{V_s} \right\rvert$						
	Present System						
360 Hz	0.4374	0.5815	0.5351	0.0466	0.0995	0.0726	0.0340
720 Hz	0.2205	0.0344	0.0074	0.0031	0.0071	0.0061	0.0030
1800 Hz	0.0884	0.0013	0.0004	0.0002	0.0004	0.0004	0.0001
New/Old (360 Hz)		0.75	0.82	9.3	4.4	6.0	12.9
L_1(mH)	1.00	1.00	1.00	1.00	10.00	5.00	10.00
L_2(mH)	0.00	1.00	10.00	10.00	1.00	1.00	1.00
C(mF)	0.00	400.00	200.00	400.00	200.00	400.00	400.00
R_a(L)	0.33	0.33	0.33	0.33	0.33	0.33	0.33
f_o(Hz)	-	251.00	356.00	251.00	100.00	112.00	80.00

As this is one of the proposed methods for reducing the ripple, it will be discussed in more detail in the following chapter.

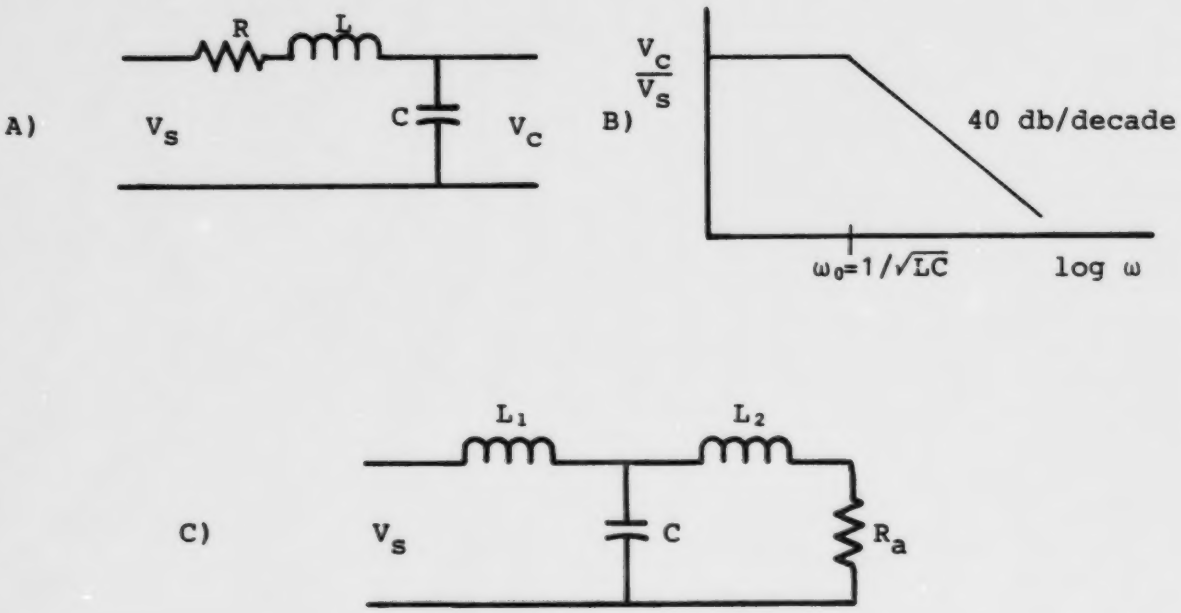


Figure 18. Second order low pass filter.

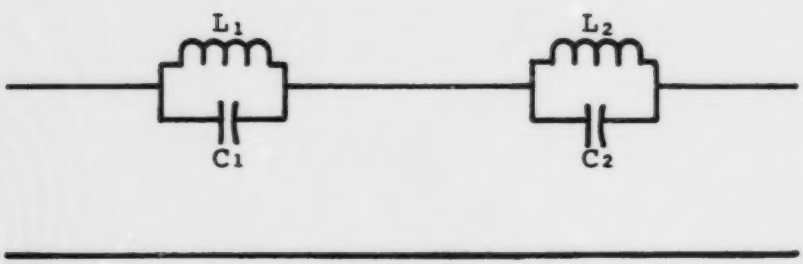


Figure 19. Resonant band stop filter.

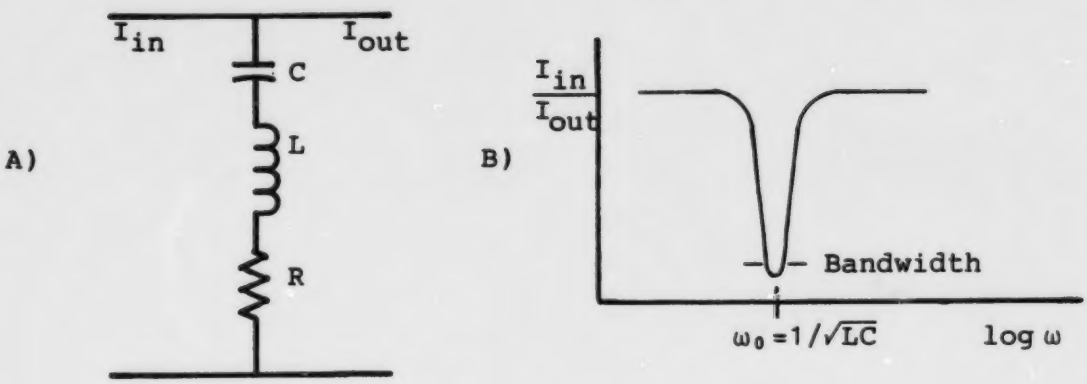


Figure 20. Resonant band pass filter.

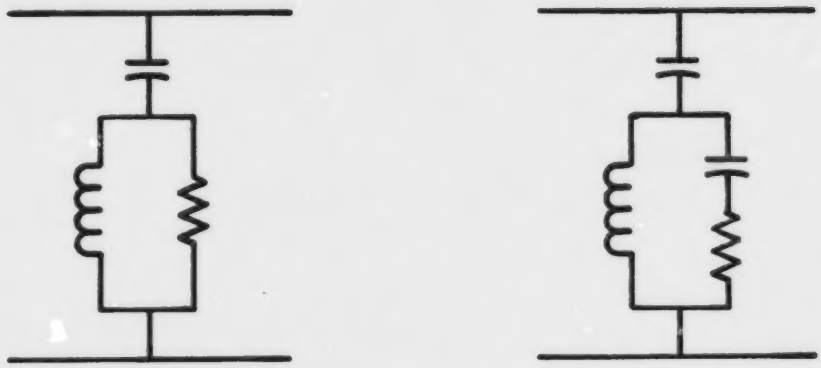


Figure 21. Higher order low pass damped filters.

10. TWO ALTERNATIVE SOLUTIONS FOR REDUCING THE HARMONICS

10.1 Proposed Solution: High Frequency Switching Power Supply

A high frequency switching power supply is the only solution if a maximum combined ripple and fluctuations of 1% is to be achieved. Simply adding a harmonic filter or replacing the SCR's with a very low ripple power supply (such as a high frequency switching power supply), will only decrease the noise in the light intensity to ~5%. In order to reduce it below 1%, the frequency response of the feedback loop will have to be raised from 0.07 Hz to probably as high as 500 Hz to 1 kHz. This is only possible with a high frequency switching power supply. The fluctuations in the light intensity, due to perturbations in the arc's gas vortex and water wall, are normally a few 360 Hz cycles in duration. The high speed transient response of the high frequency switching power supply should thus reduce the combined ripple and fluctuations to less than 1% when its ripple is less than 0.5%. The additional costs of a high frequency switching power supply over the alternate harmonics filter design (which is about 2/3 the cost) is small when considering that the 5% noise is too high for proper PV module characterization via the capacitor discharge method.

10.1.1 Proposed Design Specifications

The high frequency power supply is to be designed such that interchanging with the original SCR supply is relatively simple. This will reduce downtime in case problems arise in either supply. The specifications are as follows:

- input: 240V, 3 phase, 60 Hz
- output: approximate range: -320V @ 450A
  -195V @ 60A
  also see Table A4.

- ripple: 0.5% current (peak-peak/avg.) over the range 60A-450A

Note that the voltage ripple will be smaller as the arc's ac impedance is 0.33Ω while its dc impedance is 2.16Ω @ 100A and 0.84Ω @ 350A.

-output filter: The existing 1 mH 350A iron core inductor on the anode side will probably be used. If at all possible capacitors should not be used as they tend to excite the arc into resonance. If an LC type filter must be used, it must be multistage with as large as possible inductors and as small as possible capacitors and with a minimum of 1 mH inductance between the arc and the last capacitor. Approval of the filter design is required if capacitors are to be used.

- Protection: Standard protection practices should be used. If a fault such as an overload or short circuit (e.g. shorting bar left across arc electrodes) is detected, the default conduction should be 0 Volts and 0 Amps. Also adjustable upper and lower current limits should trip if the current exceeds these limits.

- Status Indicators: Should indicate its status and have an LED type current and voltage indicators.

- Grounding: As this is the first time a power supply of this type will be used on the arc, the anode side must be able to be either floating near ground within an RC and Varistor circuit or grounded. This option is required as the arc may not start with the anode grounded.

- Control: The power supply will derive its output state from the Vortek signal that went to its SCR firing circuit and directly controlled the SCR firing angle. There are four modes of operation:

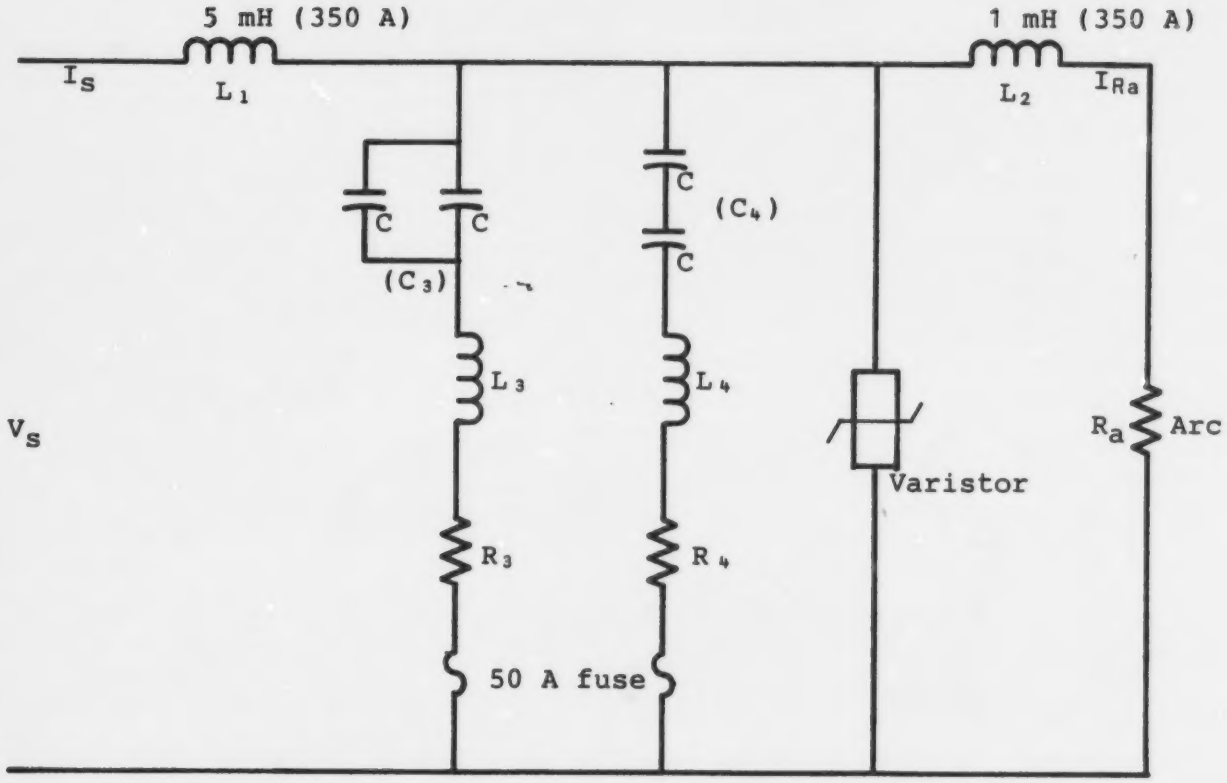
(a) 0 Volts - Standby - no voltage and current
(b) 7 volts - start-up - full volts (see next paragraph)
(c) 0 < volts <7 - fired current set by trim pot on Vortek controls (without feedback)
(d) 0 < volts <7 - photodiode feedback signal whose intensity is set by a reference trim pot.

The transient response (>500μs) should be as fast as possible while ensuring zero gain at the lowest harmonic (i.e. chopping frequency). Also, if possible, provide a second bandwidth limit for large deviations such as +/- 10% with a response <0.05 Hz.

- Starting: In start-up mode the control voltage will be 7V. This means that 320 volts must be applied to the starting circuit and lamp. As the starting -40 kV pulse is applied in series on the cathode side, the transient effect on the power supply will be negligible due to its on state impedance. Also a sustaining voltage is applied directly to the arc's electrodes and does not appear at the power supply. Once the arc has been initiated by the pulse and the discharge of the sustaining voltage capacitor, the power supply current at full voltage will be ~70A due to a series resistance. Once the arc is stabilized, the H.V. contactor closes, supplying the pre-set current (manual)/irradiance (feedback mode).

10.2 Alternate Solution: Dual Resonant Trap Harmonic Filter

The most cost effective filter is a combination of two series inductors and two resonant traps in shunt as shown in Figure 22. In this type of design, the costs of the filter components are minimized by concentrating on the two largest harmonics (i.e. 360 Hz and 720 Hz) which reduces the size and energy capacity of the inductors and capacitors. Also the energy losses due to the filter are negligible. This harmonic filter



Component List:

C = 100μF, 100 Amps r.m.s., 1kVdc (C_3 = 200μF; C_4 = 50μF)

$L_3 = L_4$ = 0.977 mH, 100 Amps r.m.s., 2.5kVdc

$R_3 = R_4$ = 0.025Ω

R_a = 0.33Ω

Varistor - V421BA60, 420 VAC, 560 Vdc, max. clamping 1160 Vdc

Figure 22. Dual trap harmonic filter.

will reduce theoretically the ripple to below ½%, but due to tuning and other factors discussed in the following section will only reduce the ripple to less than 1.5%. With the harmonic filter, the SCR timing circuit must be replaced with a phase-lock-loop firing circuit to eliminate the 60 Hz frequency components. The combination of the new firing circuit and the harmonic filter will reduce the total ripple and fluctuations in the light intensity to below 5% where the arc instabilities should dominate.

10.2.1 Design Considerations

In order to settle on a near optimum design, the following requirements had to be balanced:

- minimum total components cost
- location of undesired resonances
- voltages across components at desired resonances
- maximize harmonic reduction
- maximize useful bandwidth at desired resonances

The frequency response of the total circuit is shown in Figure 23. Two additional resonant frequencies appear at 253.6 Hz, caused by the 360 Hz trap, and at 614.5 Hz caused by the 720 Hz trap. These two frequencies are not near any existing harmonic frequency and therefore can be ignored. As the voltage across an inductance is proportional to its inductance, a higher trap inductance value results in a voltage across the inductor and capacitor (at its tuned frequency) several times greater than the harmonic's voltage at the SCR. Therefore, a low inductance value was chosen to minimize the voltage across the trap's

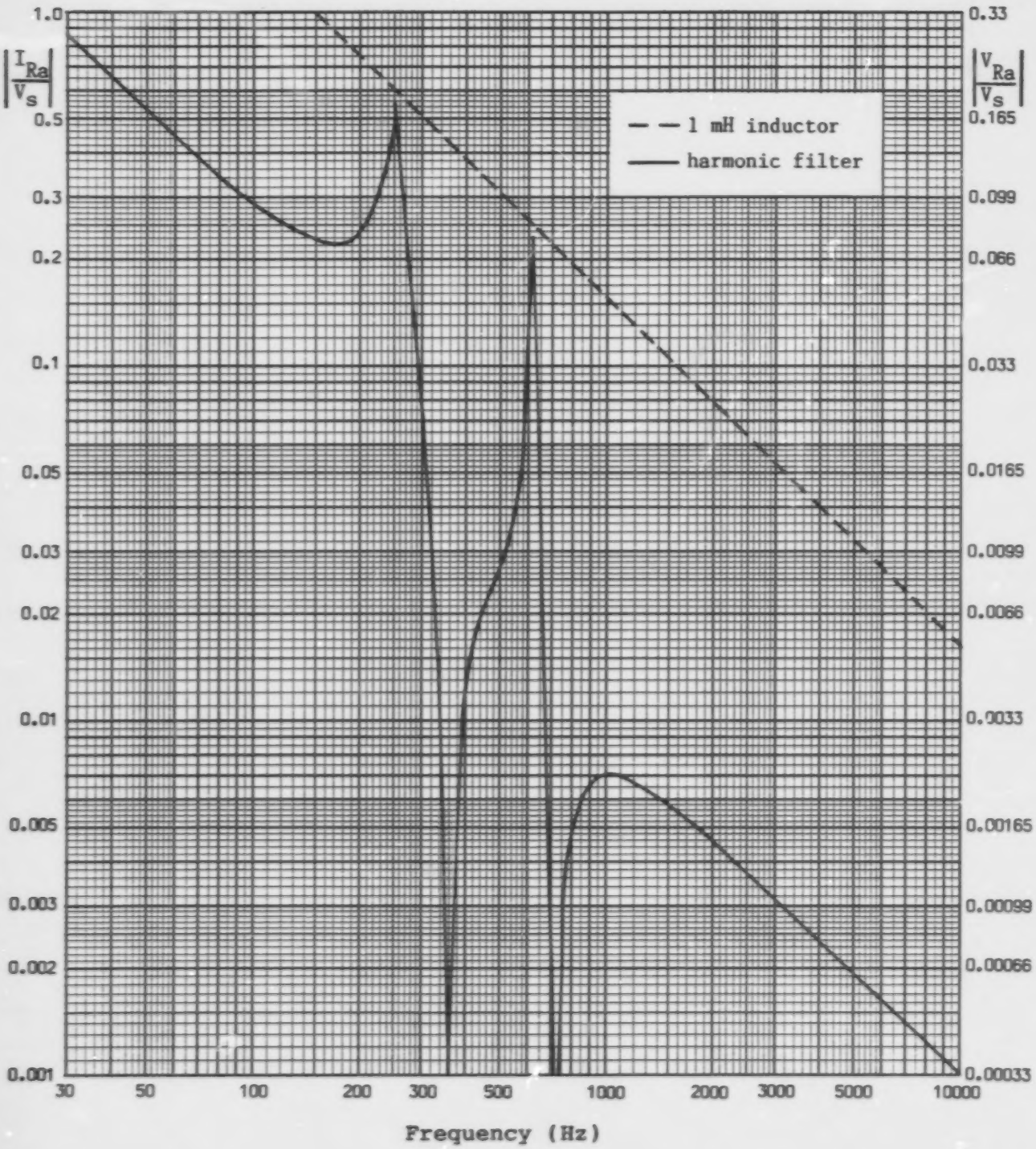


Figure 23. Frequency response of the dual trap harmonic filter.

inductor and capacitor at resonances as seen in Table 5. Also, the lower the inductance, the farther the undesired resonant frequencies are from any existing harmonic frequency. The low trap inductance is required to maximize the bandwidth and the attenuation of the trap's resonant harmonic. This requirement is caused by the arc's low dynamic resistance which forces the damping resistors to be a magnitude lower than its dynamic resistance.

The effect of removing the inductor (L1) between the SCR's and the traps, results only in an increased current flowing through the traps and an increase in the magnitude of the arc's ripple. The impedance of the inductor (L2) in series with the arc's dynamic impedance increases this total impedance to 2.59Ω and 4.85Ω at 360 Hz and 720 Hz respectively, in comparison to the resonant trap impedance of 0.025Ω.

From the simulated data in Appendix B, the theoretical maximum ripple will be:

0.54% @ 100A
0.23% @ 250A
0.10% @ 350A

This can only be achieved if the values of C3, C4, L3 and L4 are within 2% of the calculated values. The two traps could be tuned by wound air core inductors placed in series with the iron core inductors. If necessary, tuning capacitors could also be added in parallel to the main capacitors. As the 360 Hz and 720 Hz components only have to be reduced below the 1080 Hz component value, precise tuning of the traps is not critical. The projected ripple will be reduced to less than 1.5% above 100A, when considering all the above factors.

Table 5: Summary of Harmonic Filter Calculations

Frequency (Hz)	$\left\|\frac{I^*_Q}{V_s}\right\|$	$\left\|\frac{I_s}{V_s}\right\|$	$\left\|\frac{I_{Ra}}{V_s}\right\|$	$\left\|\frac{I_s}{I_{Ra}}\right\|$
360	.4375	.0884	.00097	453.1
720	.2205	.0442	.00024	905.3
1,080	.1472	.0281	.00702	21.0
1,440	.1105	.0209	.00604	18.3
1,800	.0883	.0167	.00507	17.4
2,160	.0737	.0139	.00433	17.0
2,520	.0632	.0119	.00376	16.8
2,880	.0553	.0104	.00332	16.7
3,240	.0491	.0093	.00297	16.6
3,600	.0442	.0083	.00268	16.5
10,800	.0147	.0028	.00091	16.3

Frequency (Hz)	$\left\|\frac{V_{C3}}{V_s}\right\|$	$\left\|\frac{V_{L3}}{V_s}\right\|$	$\left\|\frac{V_{C4}}{V_s}\right\|$	$\left\|\frac{V_{S4}}{V_s}\right\|$
360	.1951	.1951	.0029	.0009
720	.0004	.0015	.1953	.1953
1,000	.0066	.0511	.0479	.0923
1,800	.0024	.0598	.0109	.0684
10,000	.0001	.0616	.0003	.0618

360 Hz trap	f_o = 360 Hz Q = 88 Bandwidth = 4 Hz	C3 = 200 μF L3 = 0.977 mH R3 = 0.25Ω
720 Hz trap	f_o = 720 Hz Q = 176 Bandwidth = 4 Hz	C4 = 50 μF L4 = 0.977 mH R4 = 0.25Ω

N.B. * Existing system with 1 mH inductor.

11. CONCLUSIONS

The following conclusions can be drawn from the experimental and theoretical results of determining a feasible method of reducing the ripple in the light intensity of the National Solar Test Facility's solar simulator.

(1) The peak-to-peak irradiance ripple defined as a percentage of the average irradiance level ranged from 90% at low irradiance levels (~250 W/m^2) to a minimum of 15% at high irradiance levels (~1200 W/m^2).

(2) The percentage irradiance ripple was identical to the percentage of ripple in the arc's current. Therefore, any changes to the magnitude of the ripple in the arc current will have an identical effect on the ripple of the arc's light intensity.

(3) The random noise superimposed on the light intensity ripple results from fluctuations in the arc's intensity. This inherent instability in the arc is caused by perturbations in the arc's gas vortex and the arc's retaining water wall. Reducing the current's ripple to less than ½% will only reduce the random fluctuations below 5%. A fast transient response, irradiance level feedback loop should be able to reduce the random fluctuations to 1%.

(4) A number of options, ranging from various types of power supplies to harmonic filtering have been examined. A high frequency switching power supply is recommended since they can be designed to have less than ½% current ripple and have a fast transient response time constant (>500μs) to meet a combined ripple and random fluctuations requirement of 1%. The alternate solution

identified was a harmonic filter which is not being recommended. The combined ripple and random fluctuations will be approximately 5% as the response time constant can not be altered for an SCR power supply, and thus the random fluctuations will not be reduced significantly.

By installing this recommended high frequency switching power supply into the solar simulator, the N.S.T.F. will then be able to test photovoltaic cells and modules by the standard high speed I-V curve scanning method. The reduced harmonics will also increase the arc's stability, resulting in longer electrode life and permitting stable operation below the present minimum irradiance level. The primary indirect beneficiary should be Vortek Industries, in the design, building and marketing of a low irradiance ripple arc lamp version.

12. RECOMMENDATIONS

As confirmed from the results of the lamp characterization, the ripple of the lamp is unacceptably high. The magnitude of the random fluctuations in the light intensity due to inherent instabilities in the arc, automatically decreases to only 5% when reducing the ripple in the current to less than 1%. To attain the combined ripple and random fluctuation requirement of 1% for photovoltaic electrical performance measurements, a high frequency switching power supply with a ripple of ½% and a transient response time constant of approximately 500μs is being recommended. The fast response time constant of the irradiance level feedback loop will control the magnitude of the random fluctuation to a maximum of approximately 1%.

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APPENDIX A

DATA ON THE LAMP'S RIPPLE

A1 - Light Intensity

A2 - Arc Current

A3 - SCR Voltage

A4 - Arc Voltage

A5 - AC Mains

APPENDIX A

Table A1: Summary of Measured Data - Light Intensity

a) Channel 1 - Silonex Cell

Arc Current (A)	Max (mV)	Min (mV)	Avg. (mV)	% Ripple	Bottom Peak to 'T' (ms)	Figure #
100	61.8 - 64.9	22.9	47.1	90.8	2.170 - 0.602	A1.1
150	108.4 - 100.7	52.8	83.9	59.4	2.435 - 0.338	A1.2
200	144.8 - 150.2	94.2	128.3	43.6	2.700 - 0.078	A1.3
250	195.0	141.5	176.3	30.2	2.947 - 0.171	A1.4
300	242.5 - 236.8	189.0	218.9	21.8	3.165 - 0.350	A1.5
350	256.0 - 252.7	216.7	239.4	16.4	3.475 - 0.650	A1.6

b) Channel 2 - Reference Cell

Arc Current (A)	Max (mV)	Min (mV)	Avg. (mV)	% Ripple	Figure #
100	33.8 - 31.75	11.5	24.8	89.1	A1.1
150	53.5 - 51.9	26.8	46.2	58.8	A1.2
200	78.7 - 75.7	49.2	68.2	43.3	A1.3
250	100.7	73.0	92.3	30.1	A1.4
300	127.6 - 125.7	99.0	116.1	23.0	A1.5
350	187.5 - 179.9	158.2	171.8	14.2	A1.6

N.B. To ensure an AC timing reference, the scope was plugged into the same outlet for all tests and used the positive slope of its AC source at 50.3 Volts as the trigger source (i.e. see "50.3 LINE" on oscillographs).

Figure A1.1 Light intensity @ 100 A.

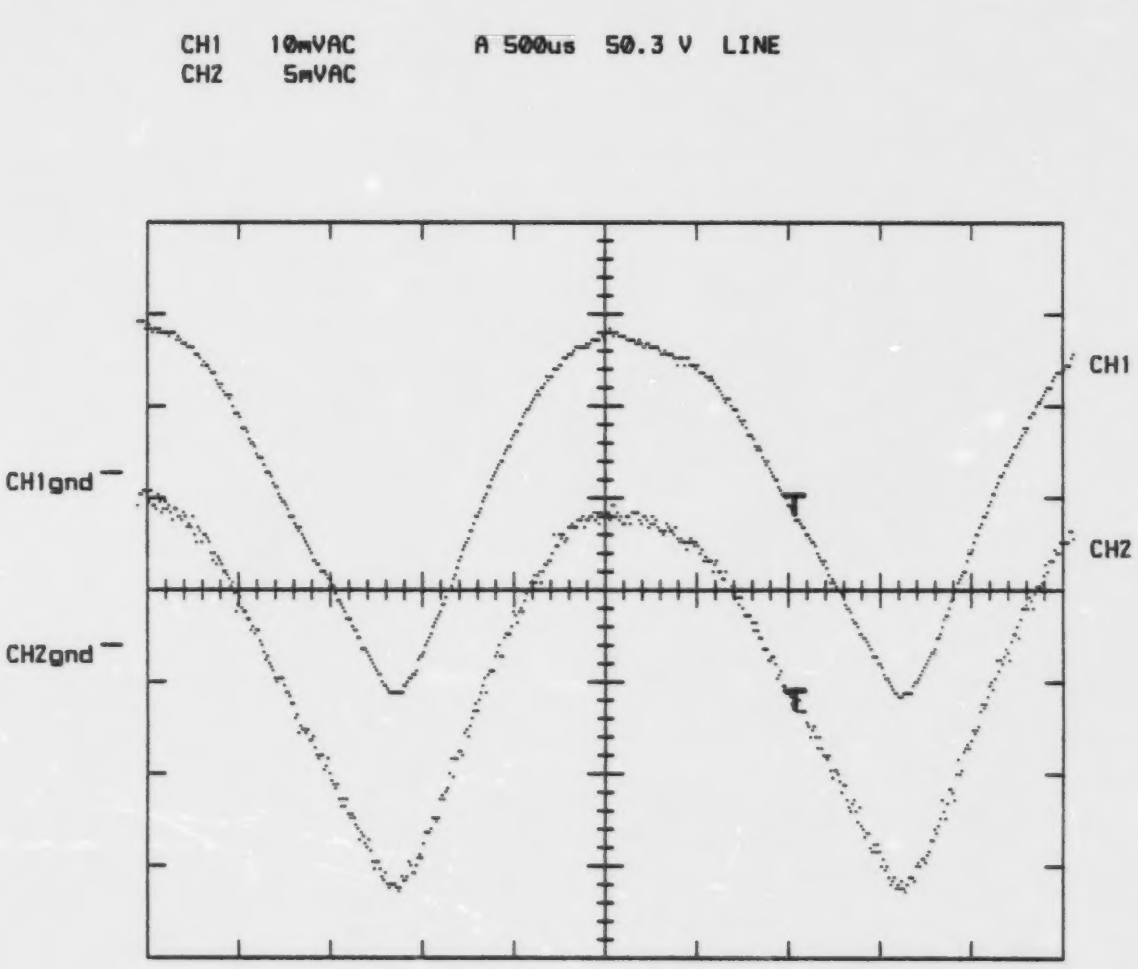


Figure A1.2 Light intensity @ 100 A.

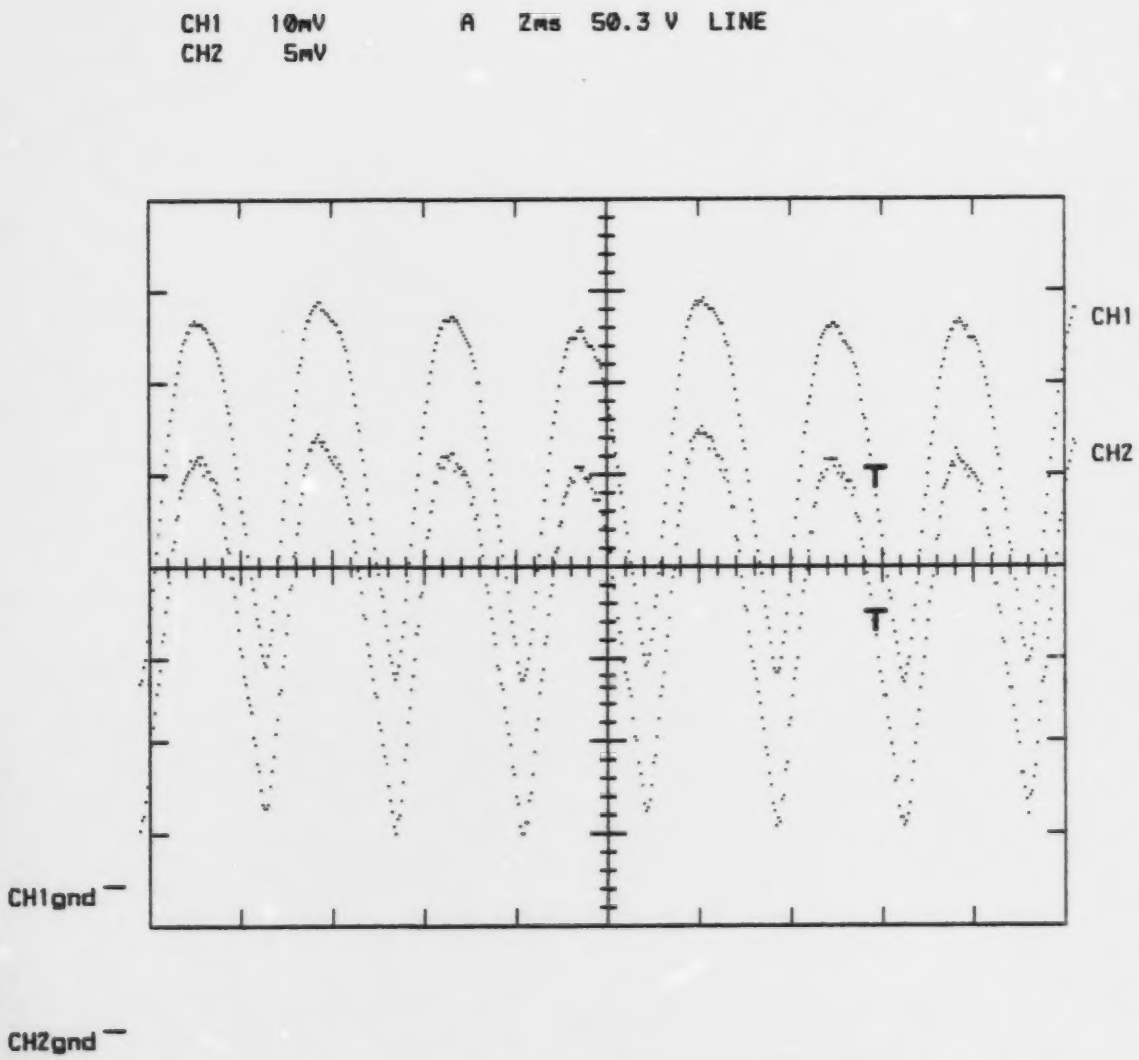


Figure A1.3 Light intensity @ 150 A.

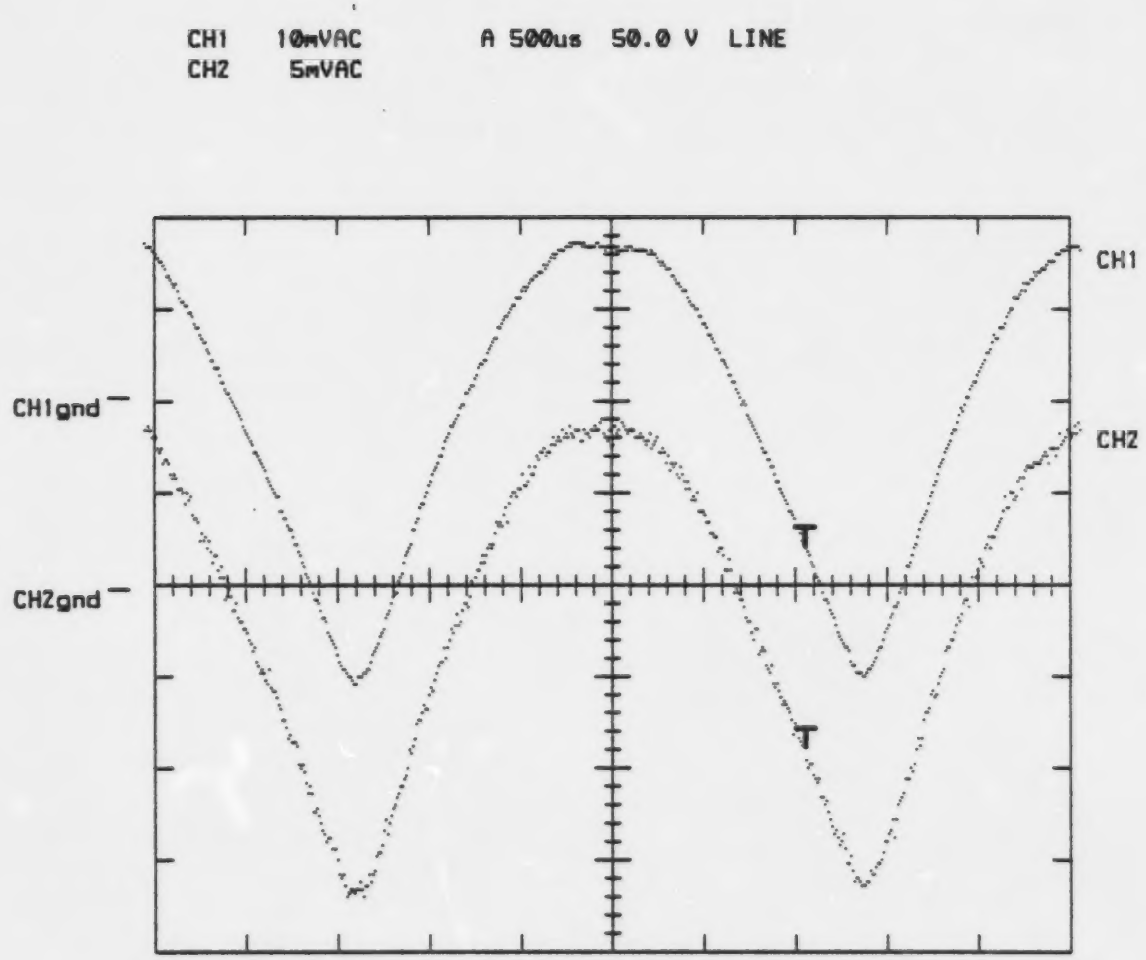


Figure A1.4 Light intensity @ 150 A.

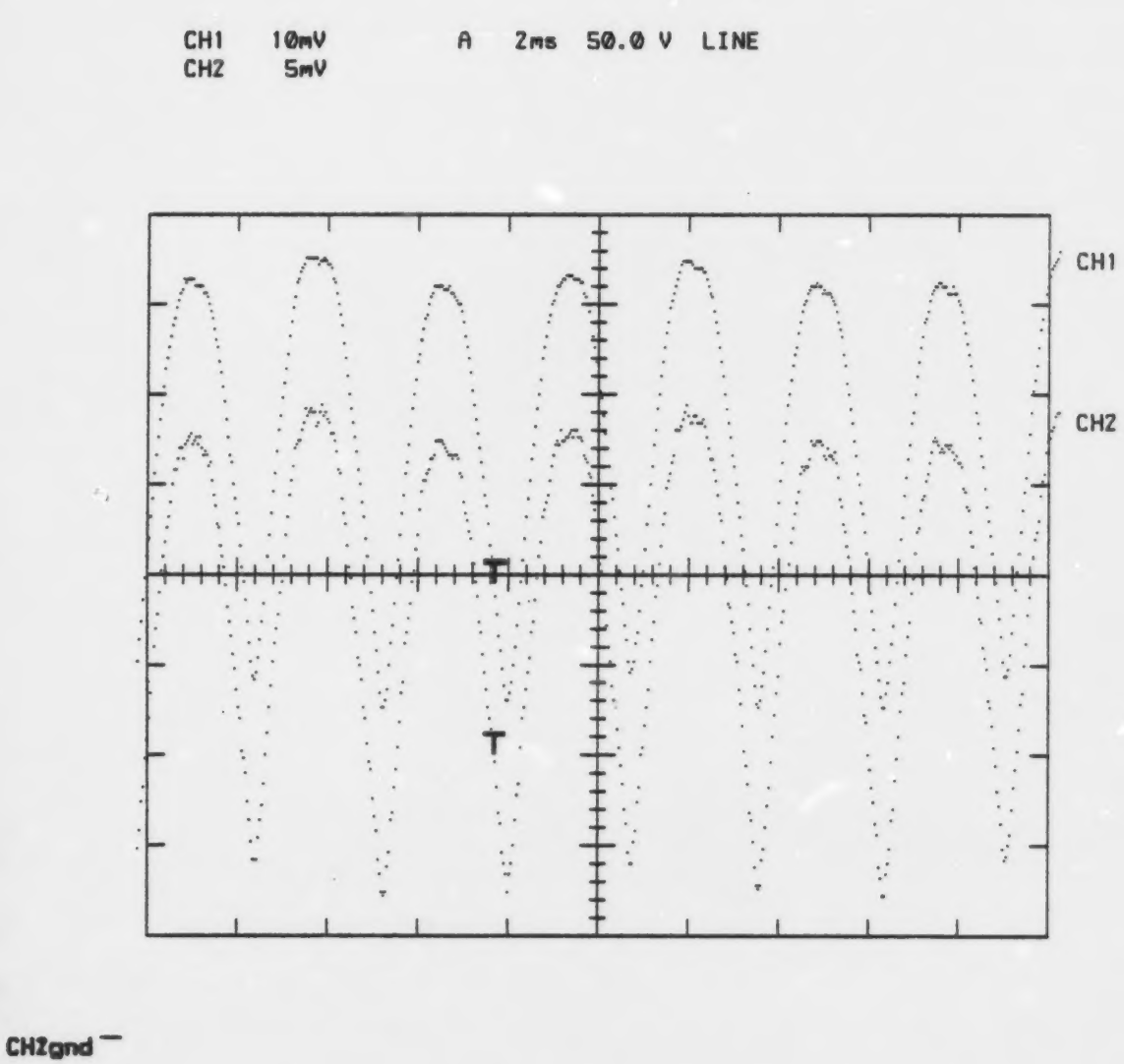


Figure A1.5 Light intensity @ 200 A.

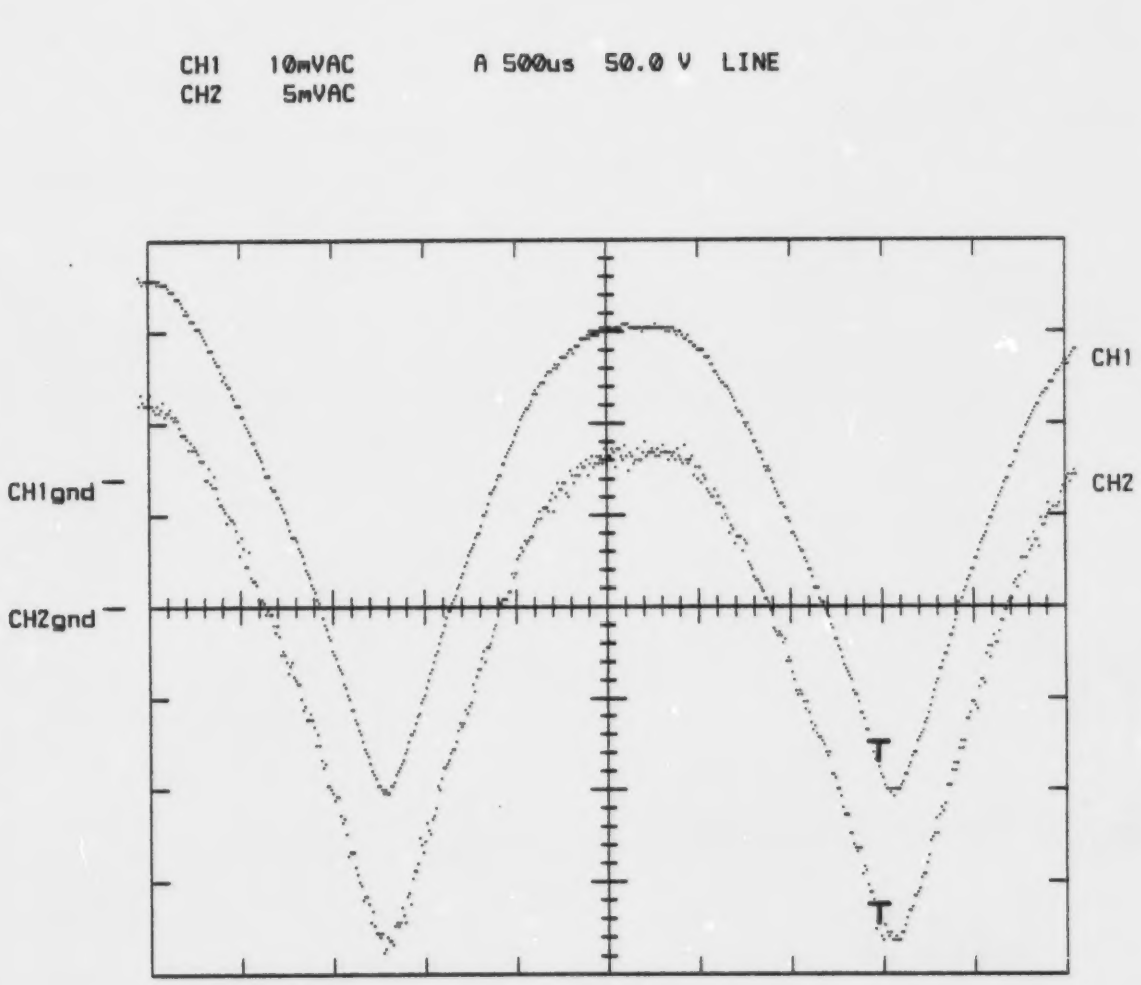


Figure A1.6 Light intensity @ 250 A.

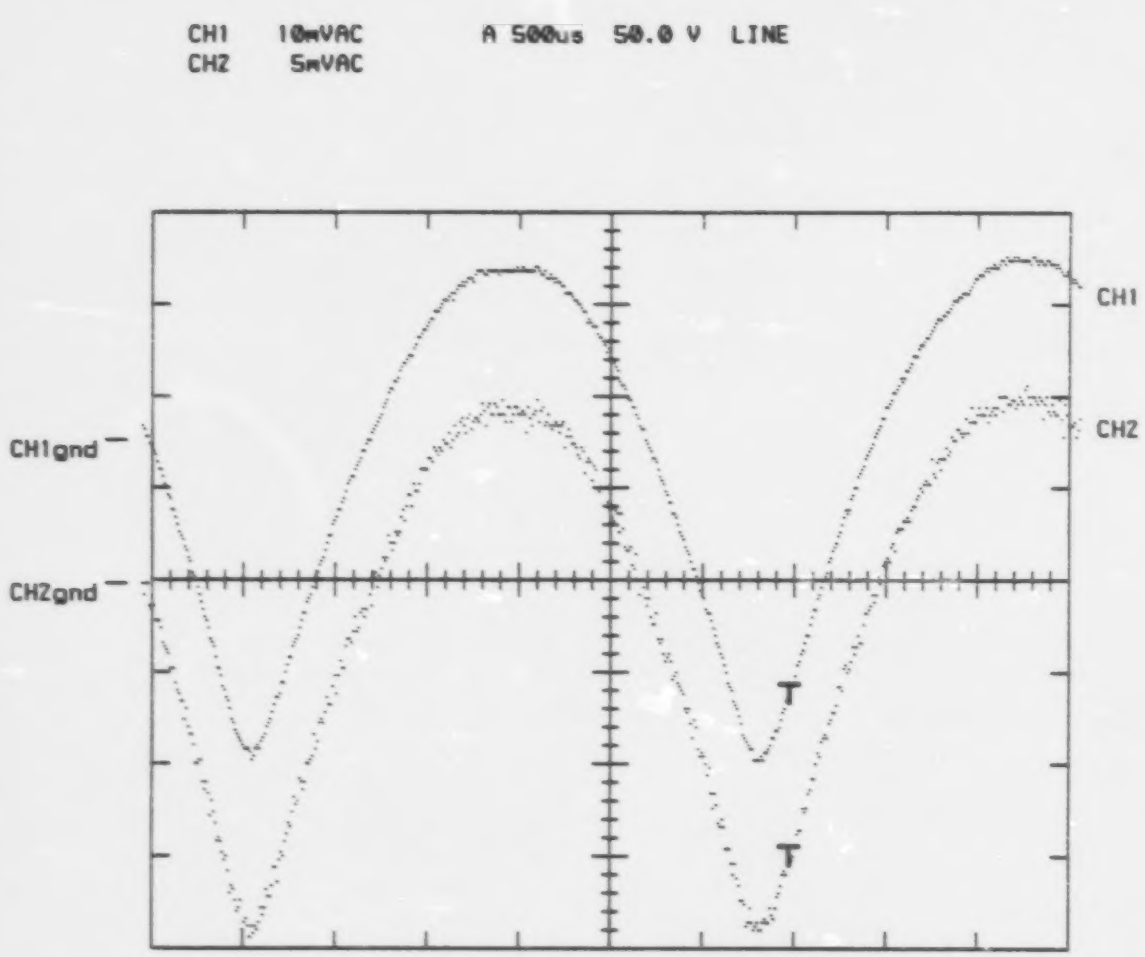


Figure A1.7 Light intensity @ 250 A.

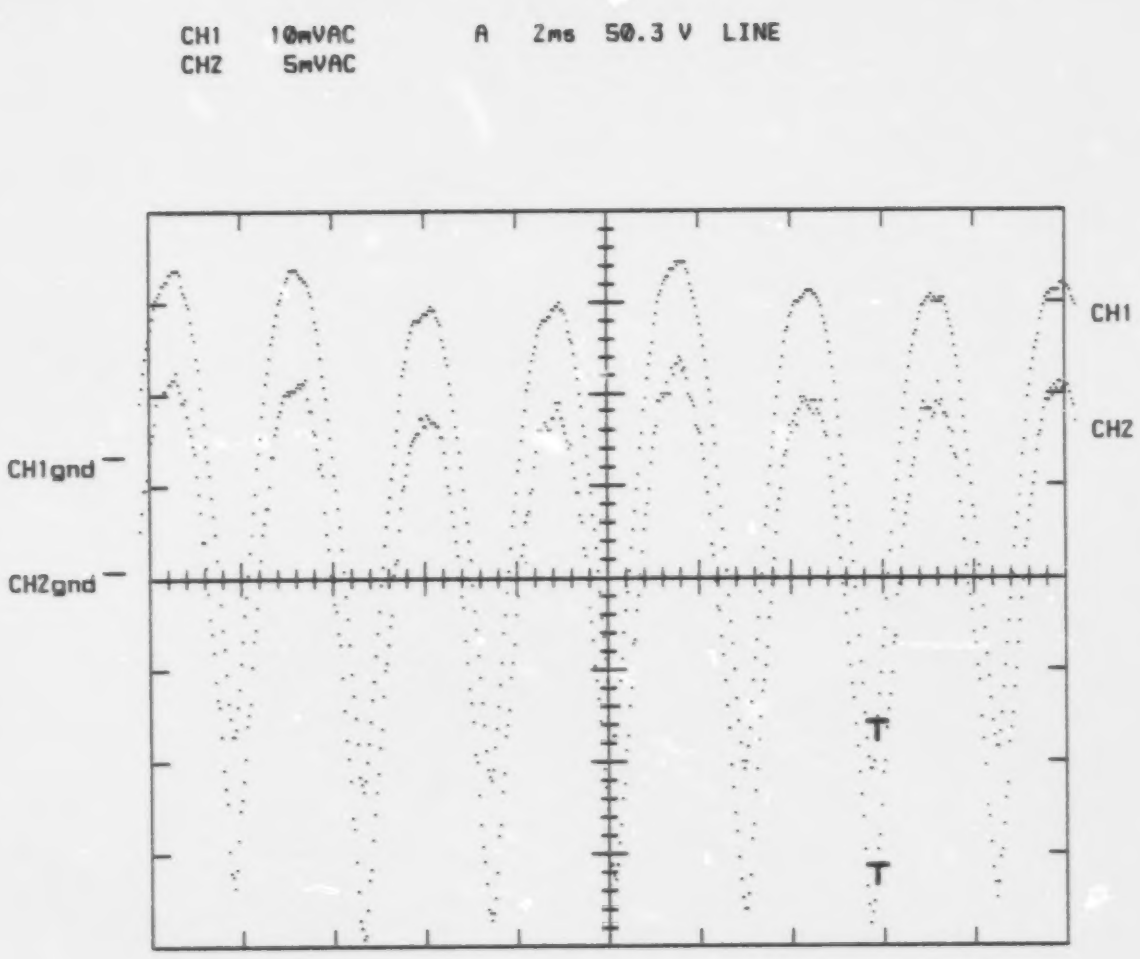


Figure A1.8 Light intensity @ 300 A.

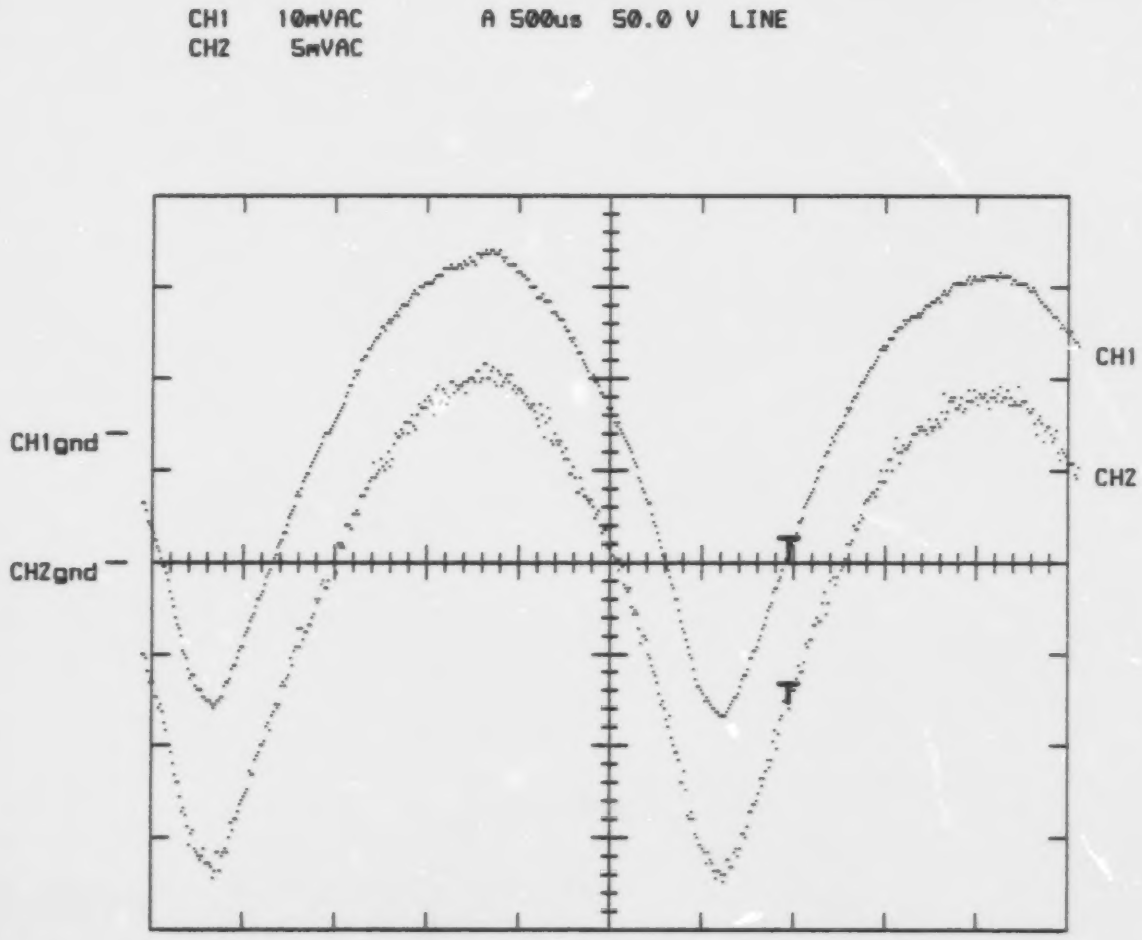


Figure A1.9 Light intensity @ 300 A.

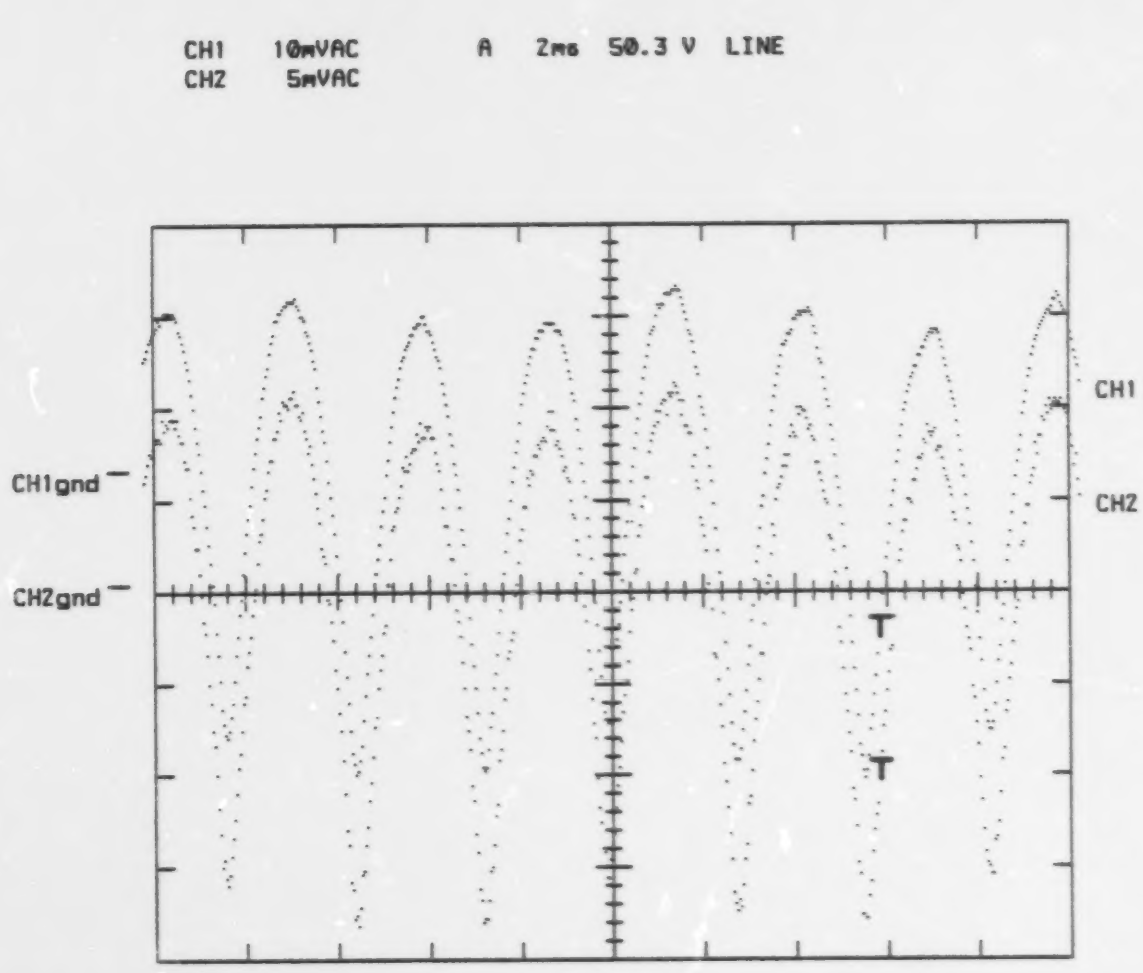


Figure A1.10 Light intenstiy @ 350 A.

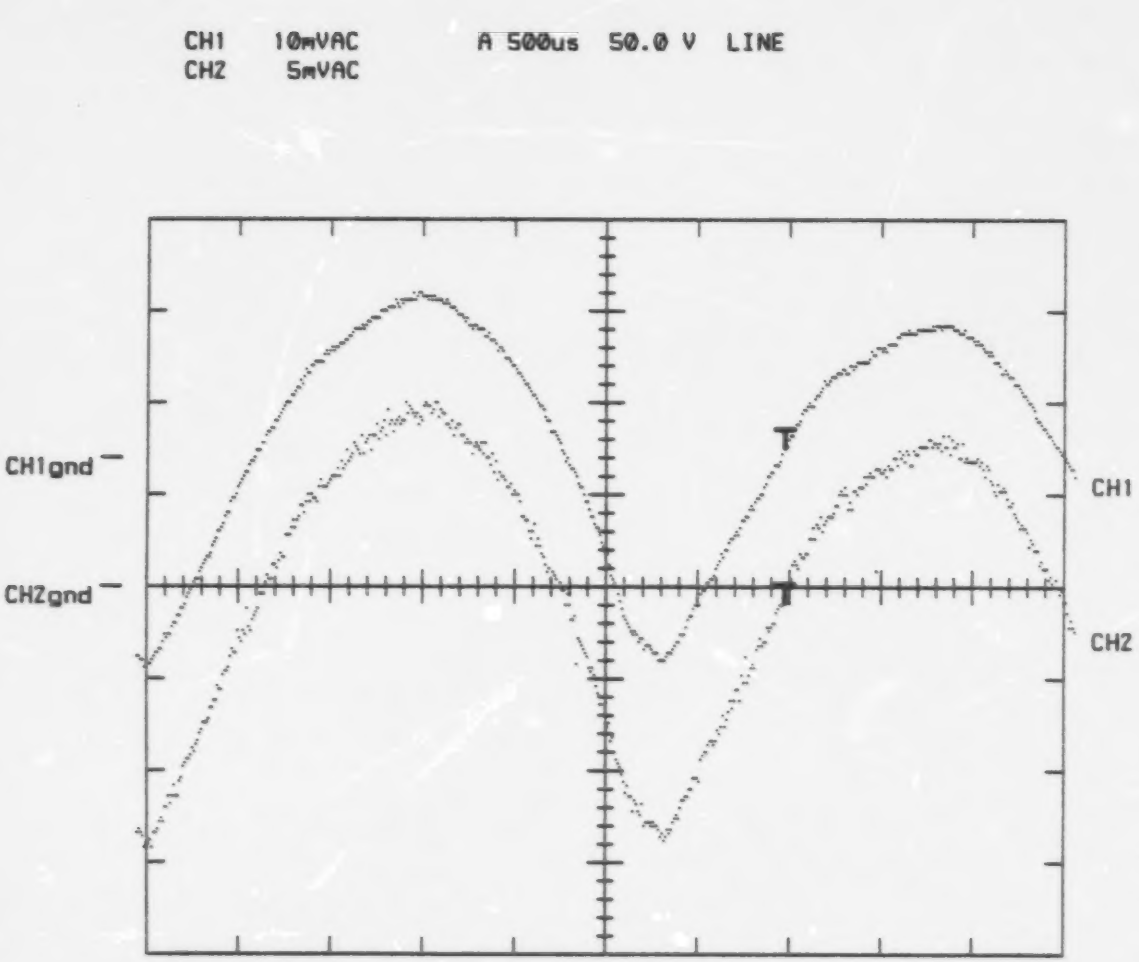


Table A2: Summary of Measured Data - Arc Current

Arc Current (A)	Max (A)	Min (A)	Avg. (A)	% Ripple	Bottom Peak to 'T' (ms)	Figure #
100	126.0 - 120.0	35.1	99.4	91.4	2.265 - 2.140	A2.1
150	171.4 - 165.4	82.2	146.2	61.0	2.492 - 2.354	A2.2
200	218.5 - 212.8	133.0	195.5	43.9	2.680 - 2.600	A2.3
250	263.5 - 258.2	187.0	244.0	31.3	2.960 - 2.838	A2.4
300	311.0 - 309.1	240.0	295.0	24.0	3.152 - 3.012	A2.5
350	355.5	304.5	343.5	14.8	3.582 - 3.365	A2.6

Figure A2.1 Arc current @ 100 A. (1V:100A)

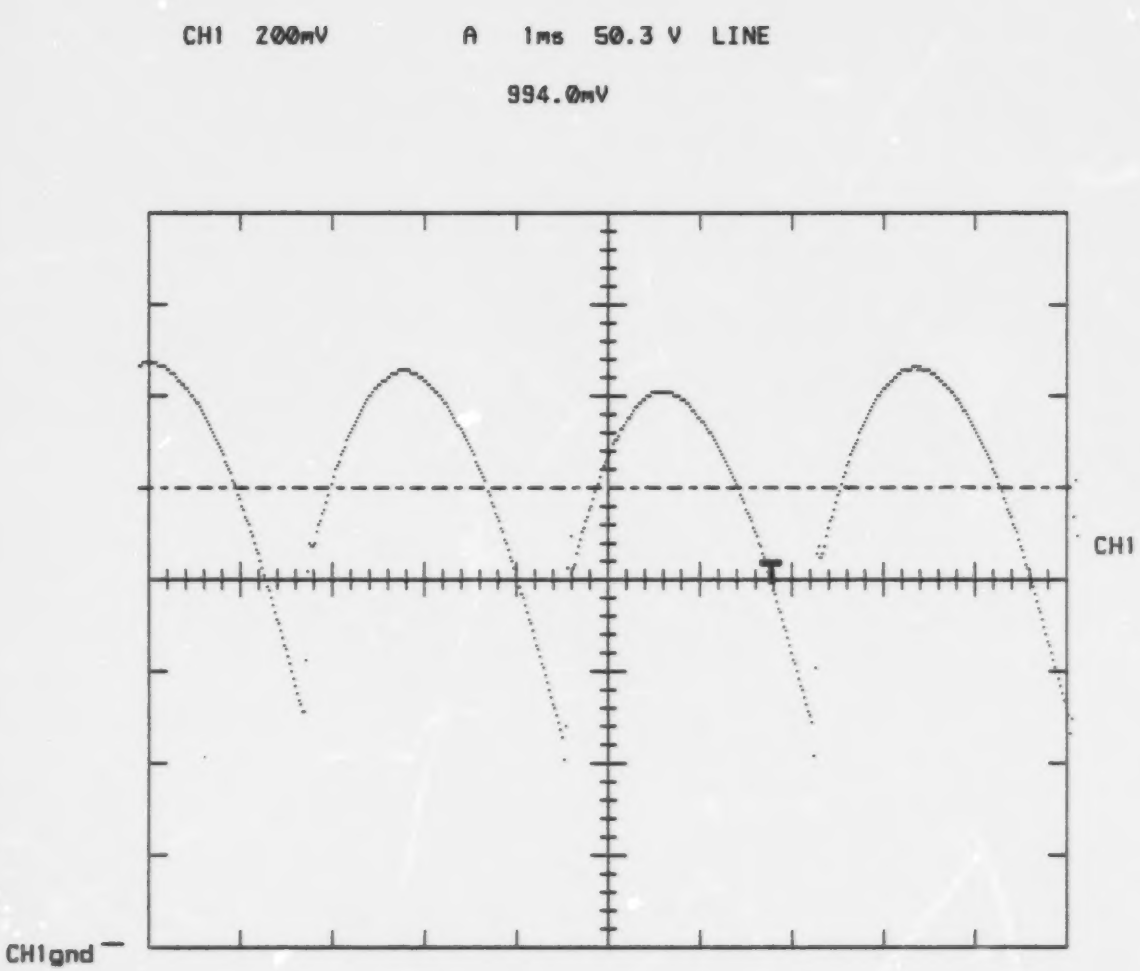


Figure A2.2 Arc current @ 150 A. (1V:100A)

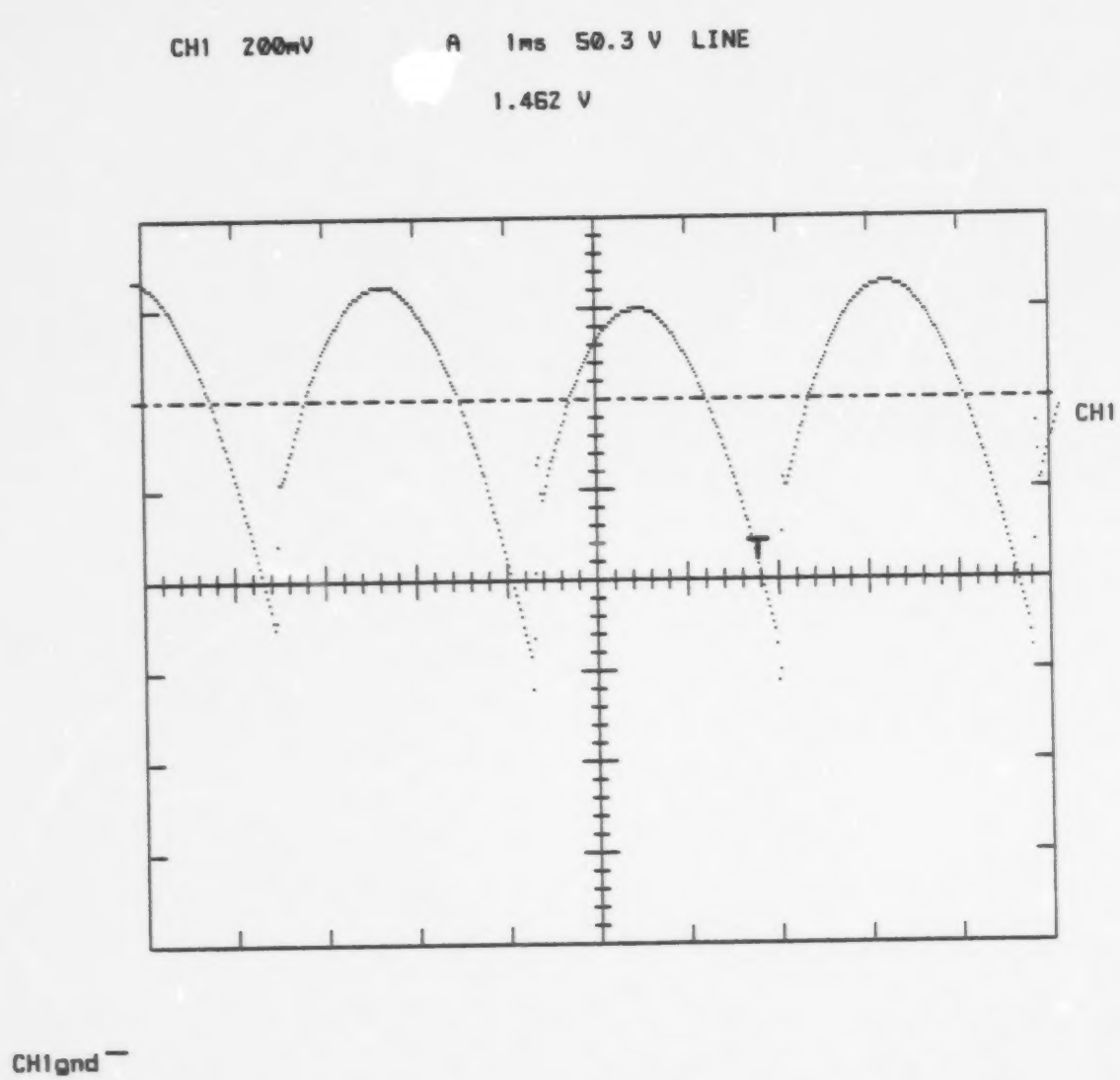


Figure A2.3 Arc current @ 200 A. (1V:100A)

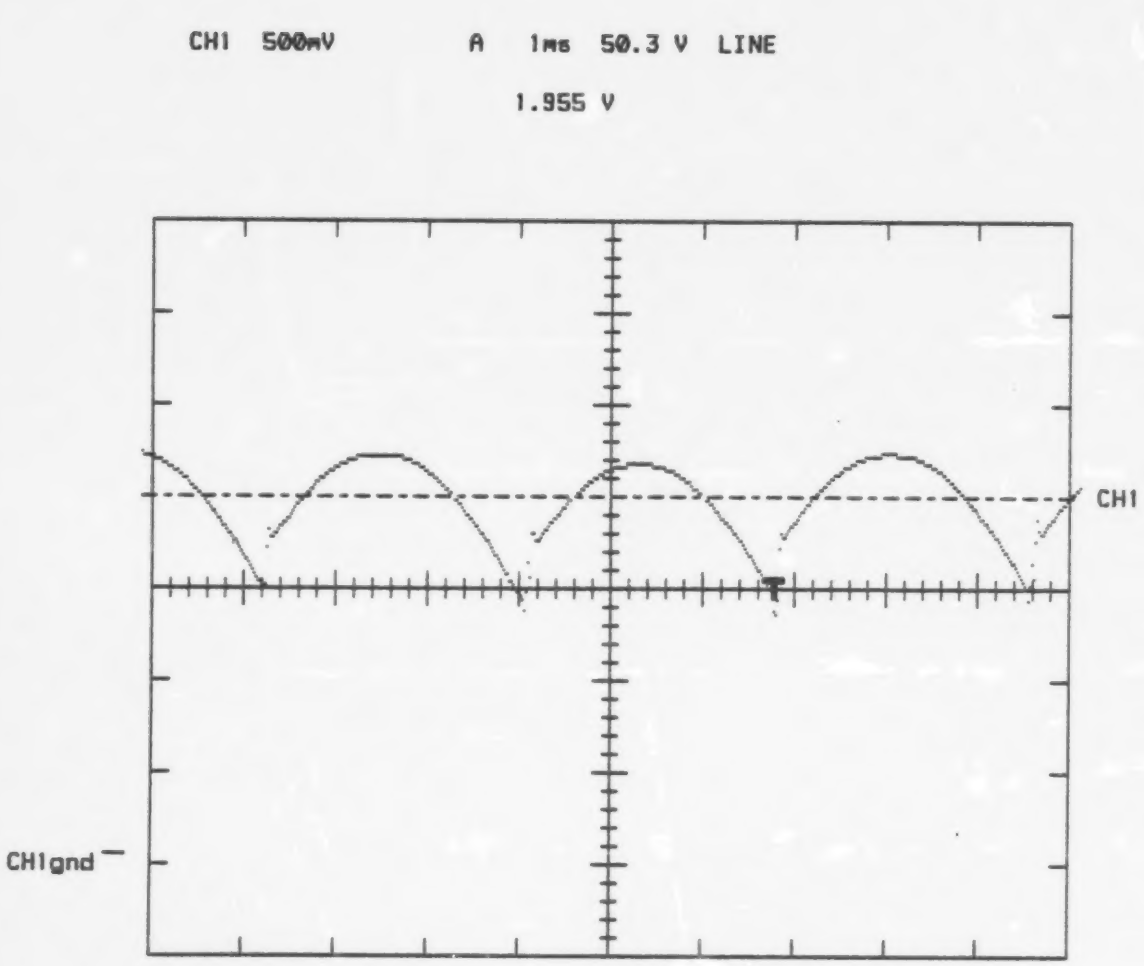


Figure A2.4 Arc current @ 250 A. (1V:100A)

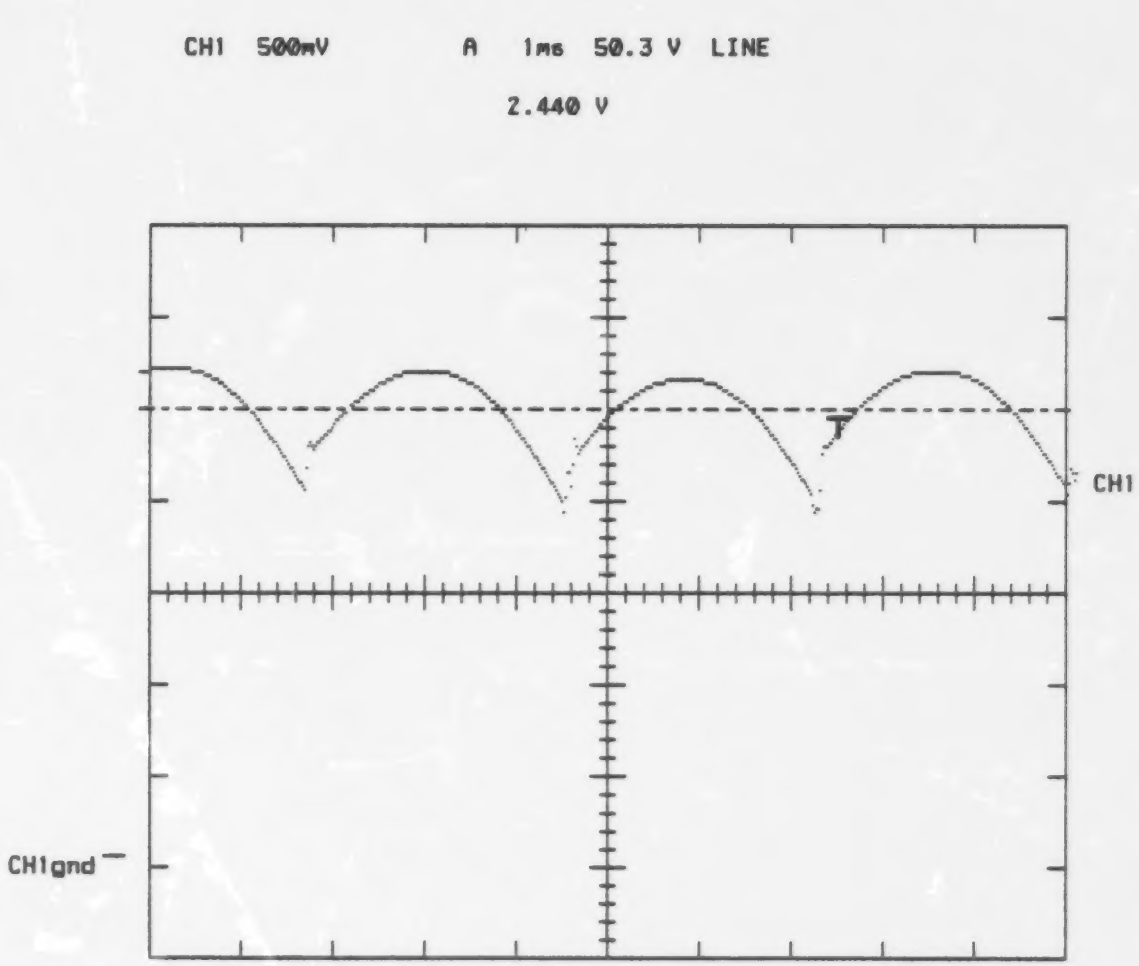


Figure A2.5 Arc current @ 300 A. (1V:100A)

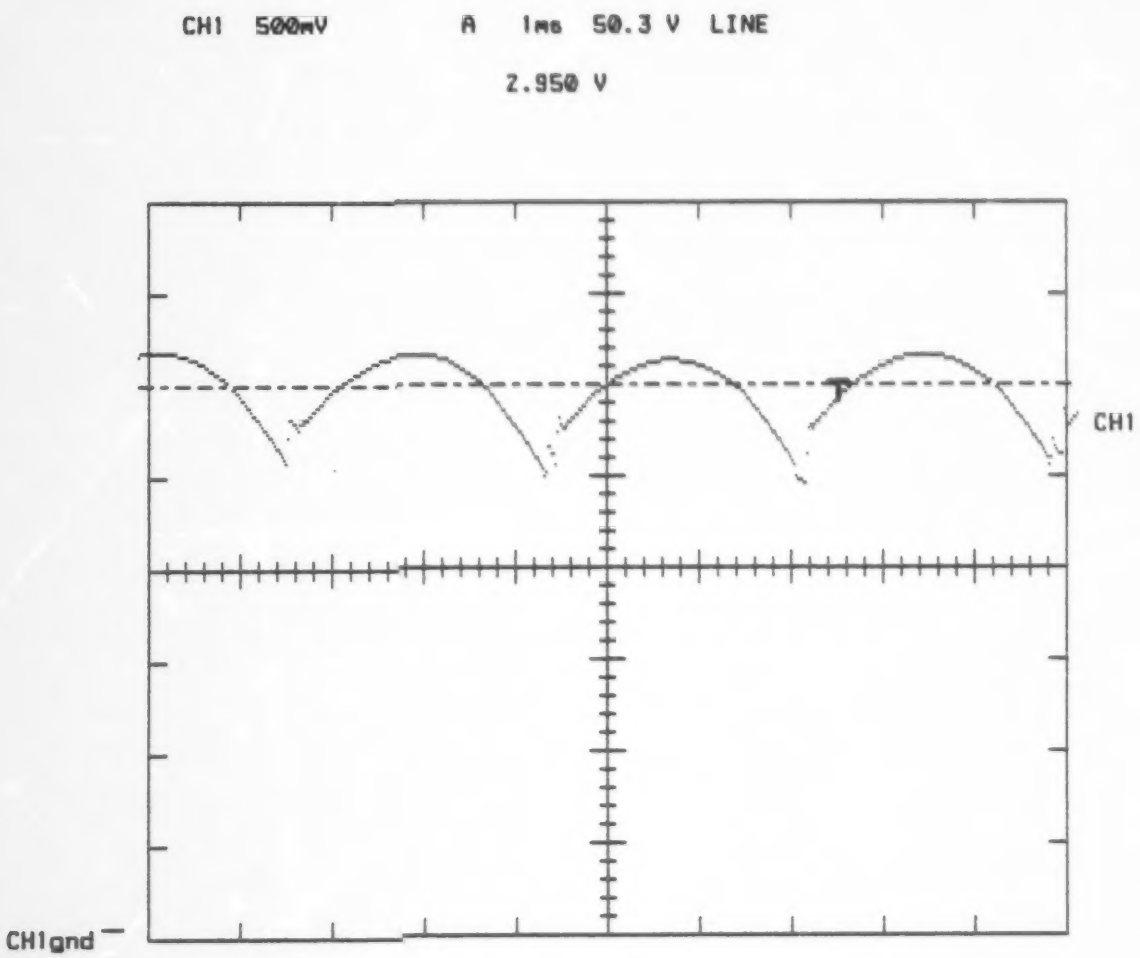


Figure A2.6 Arc current @ 350 A. (1V:100A)

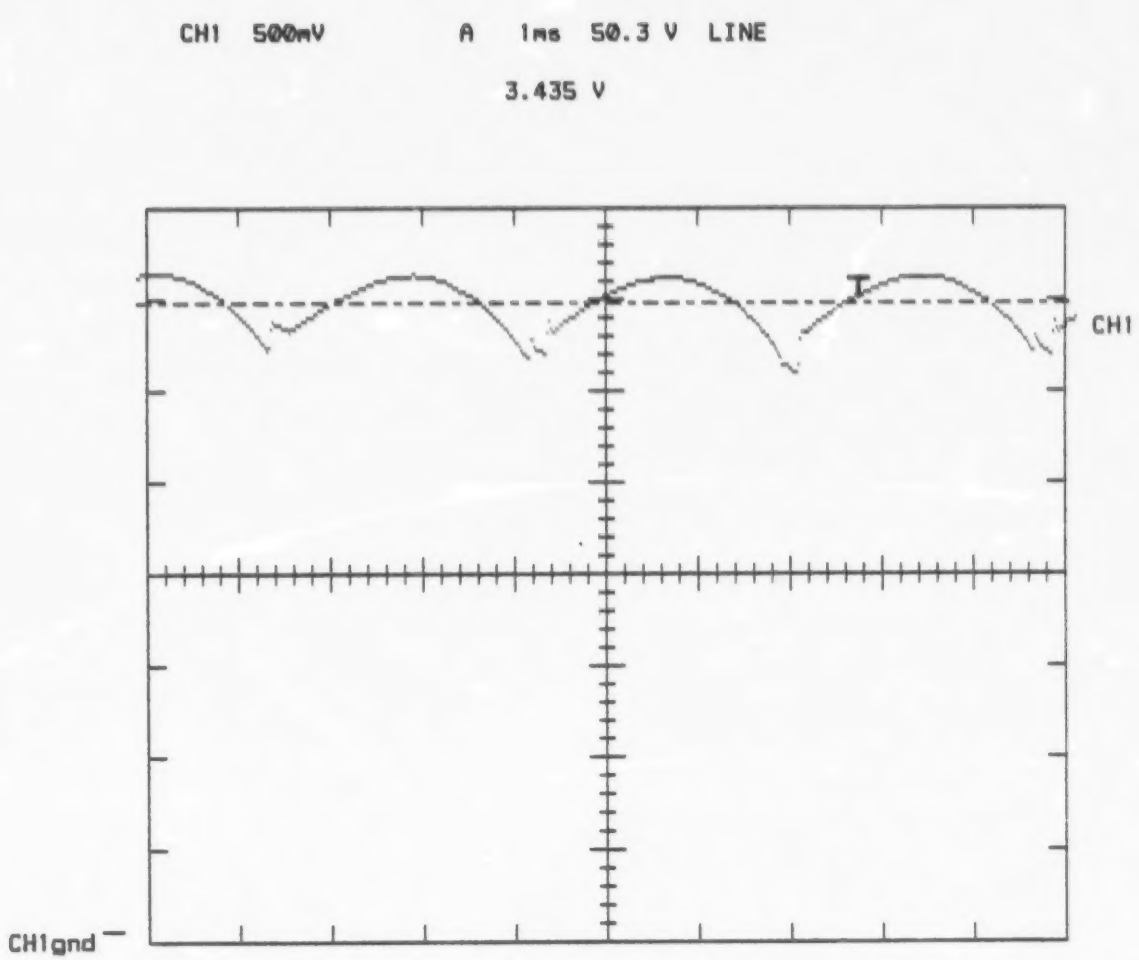


Table A3: Summary of Measured Data - SCR Voltage

Arc Current (A)	Max (-V)	Min (-V)	Avg. (-V)	% Ripple	Bottom Peak to 'T' (ms)	Figure #
100	324	80	214	112	2.258 - 2.198	A3.1
150	327	109	232	94	2.530 - 2.448	A3.3
200	330	148	250	74	2.880 - 2.634	A3.5
250	334	165	274	64	3.016 - 2.876	A3.7
300	342	190	288	53	3.238 - 3.070	A3.9
350	342	211	291	42	3.608 - 3.372	A3.11

Figure A3.1 SCR voltage @ 100 A. (1V:-100V)

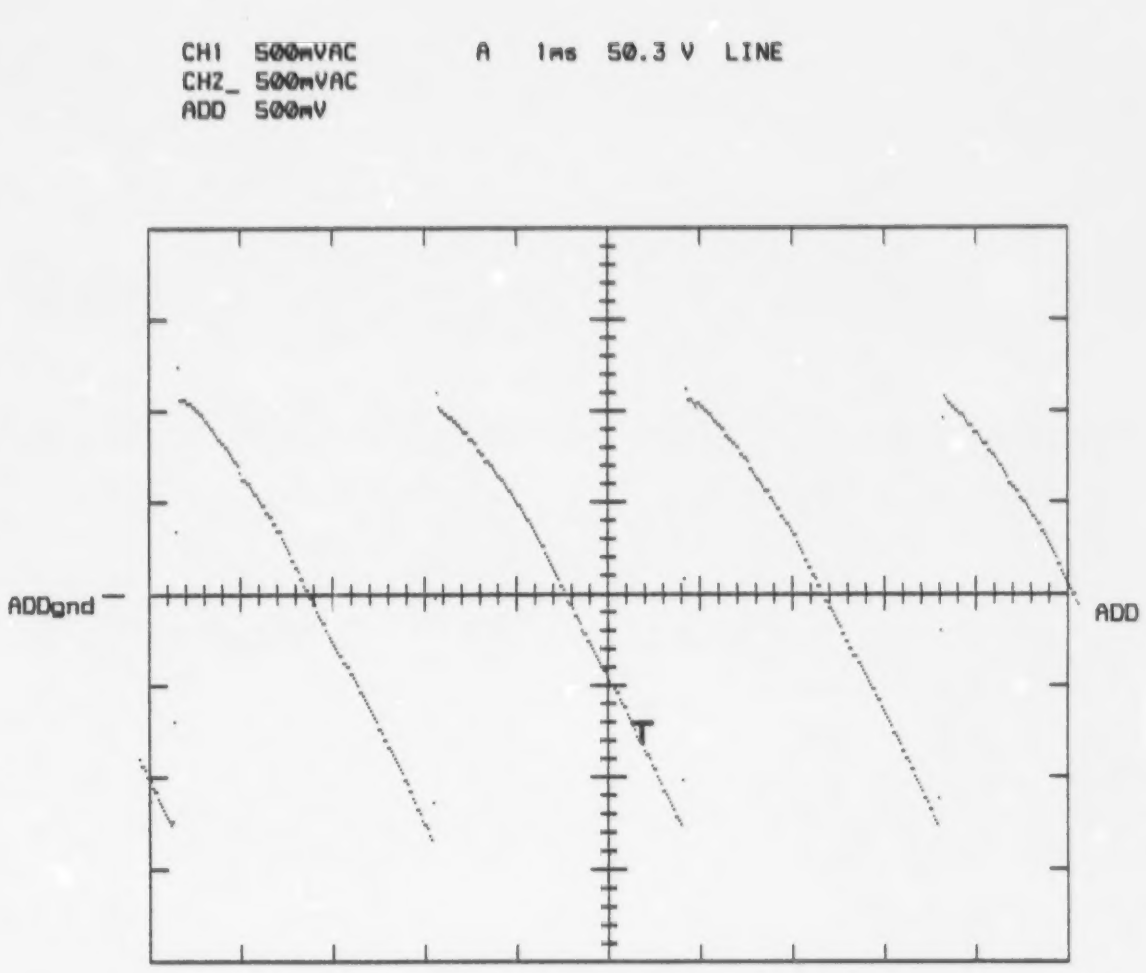


Figure A3.2 SCR voltage @ 100 A. (IV:-100V)

channel 2: cathode
channel 1: anode

CH1 500mVAC A 1ms 50.3 V LINE
CH2_ 500mVAC

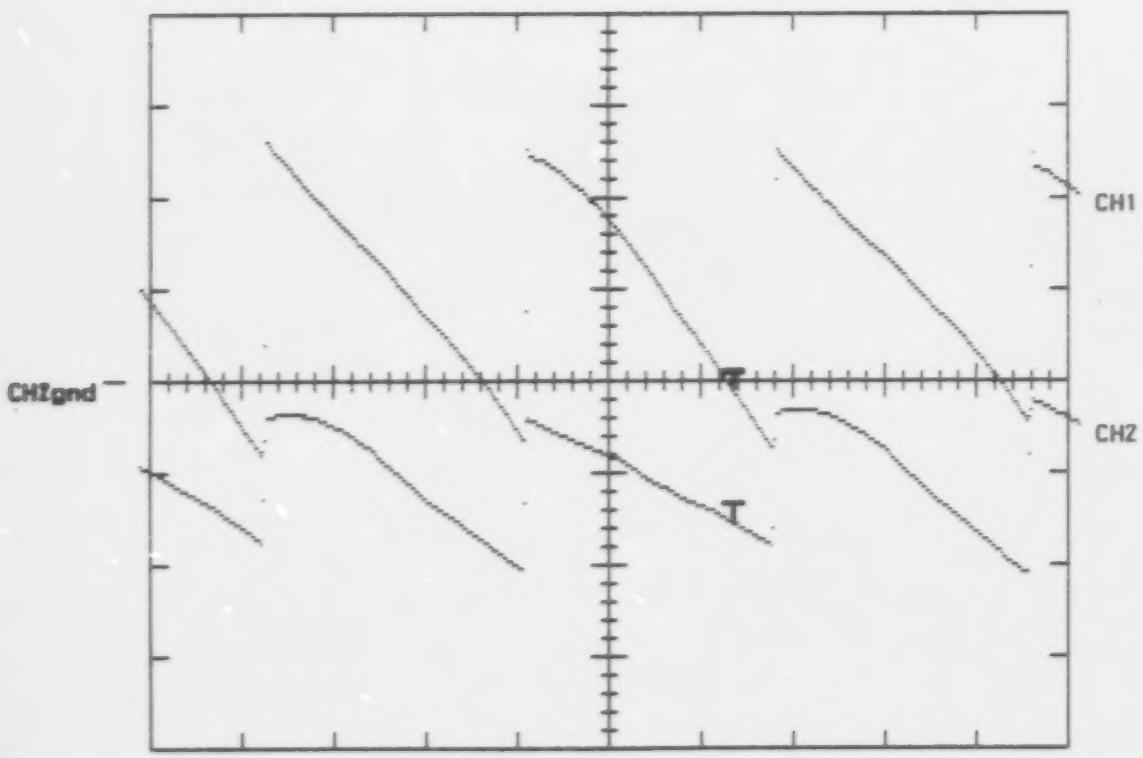


Figure A3.3 SCR voltage @ 150 A. (1V:-100V)

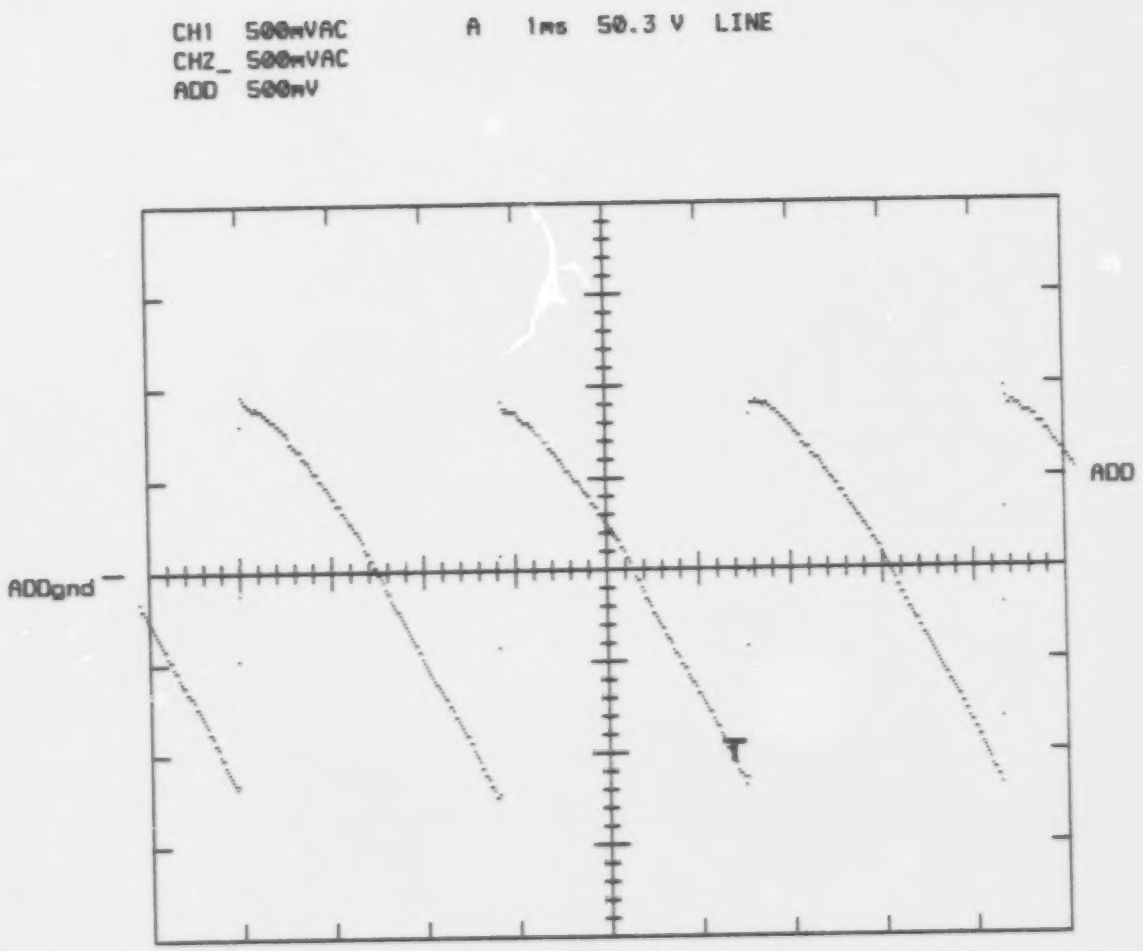


Figure A3.4 SCR voltage @ 150 A (1V:-100V)

channel 2: cathode
channel 1: anode

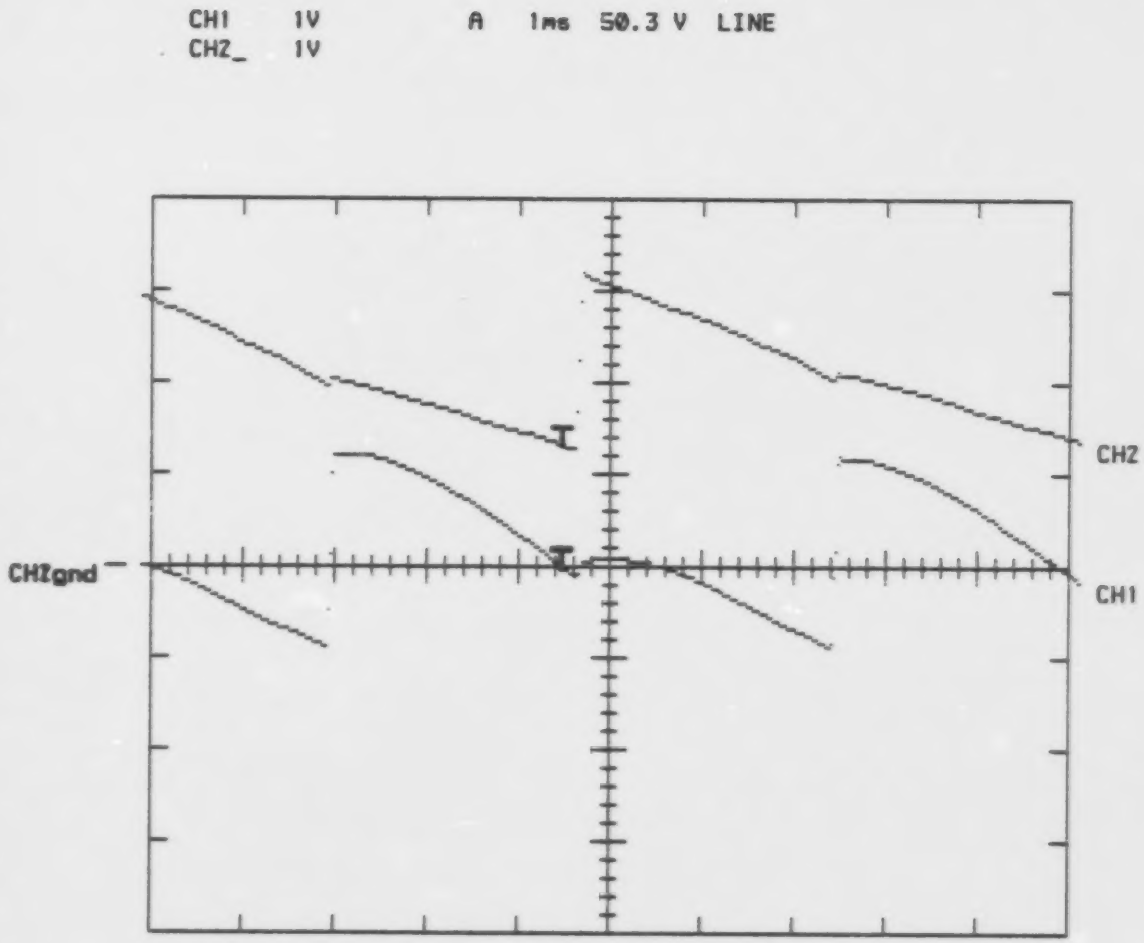


Figure A3.5 SCR voltage @ 200 A. (IV:-100V)

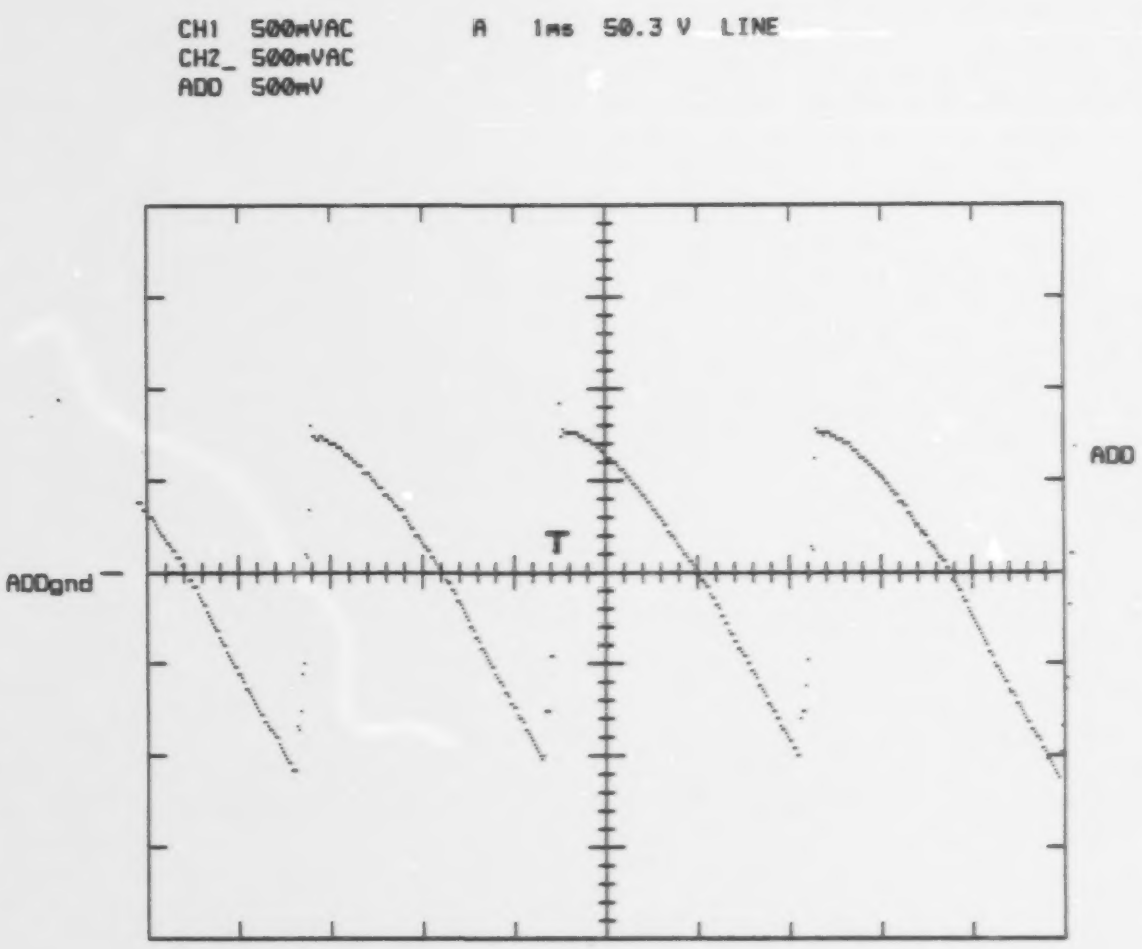


Figure A3.6 SCR voltage @ 200 A. (1V:-100V)

channel 2: cathode
channel 1: anode

CH1 1V A 1ms 50.3 V LINE
CH2_ 1V

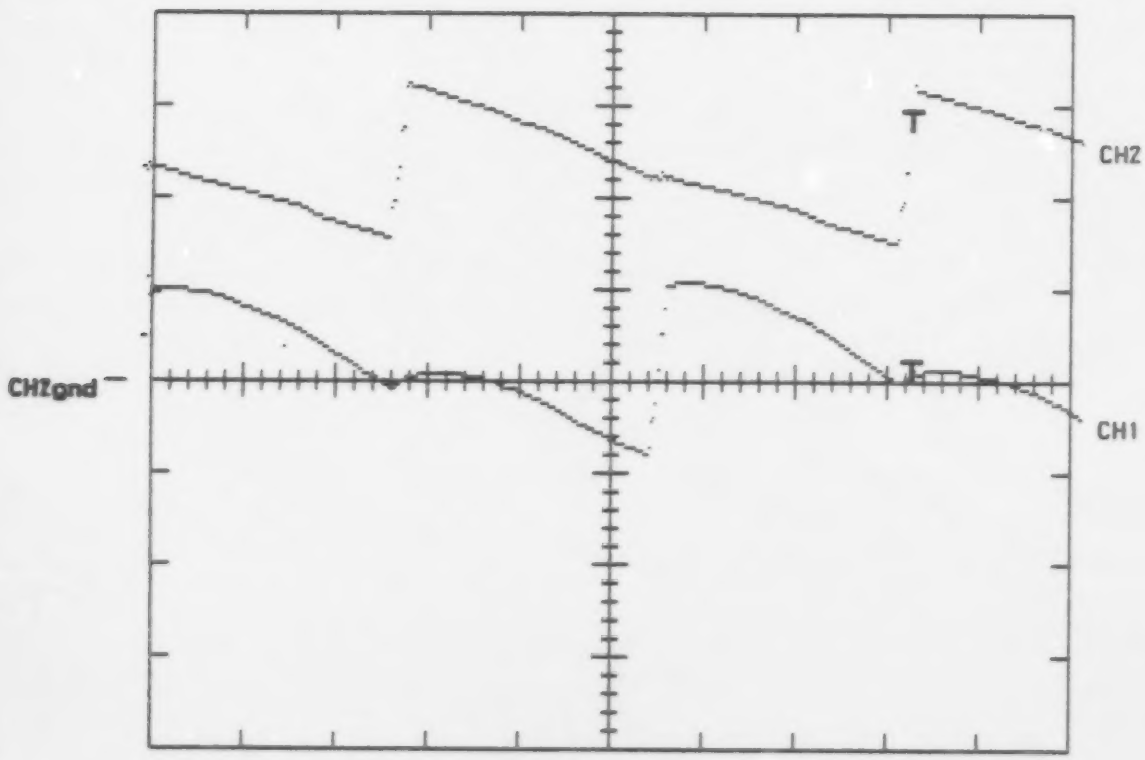


Figure A3.7 SCR voltage @ 250 A. (1V:-100V)

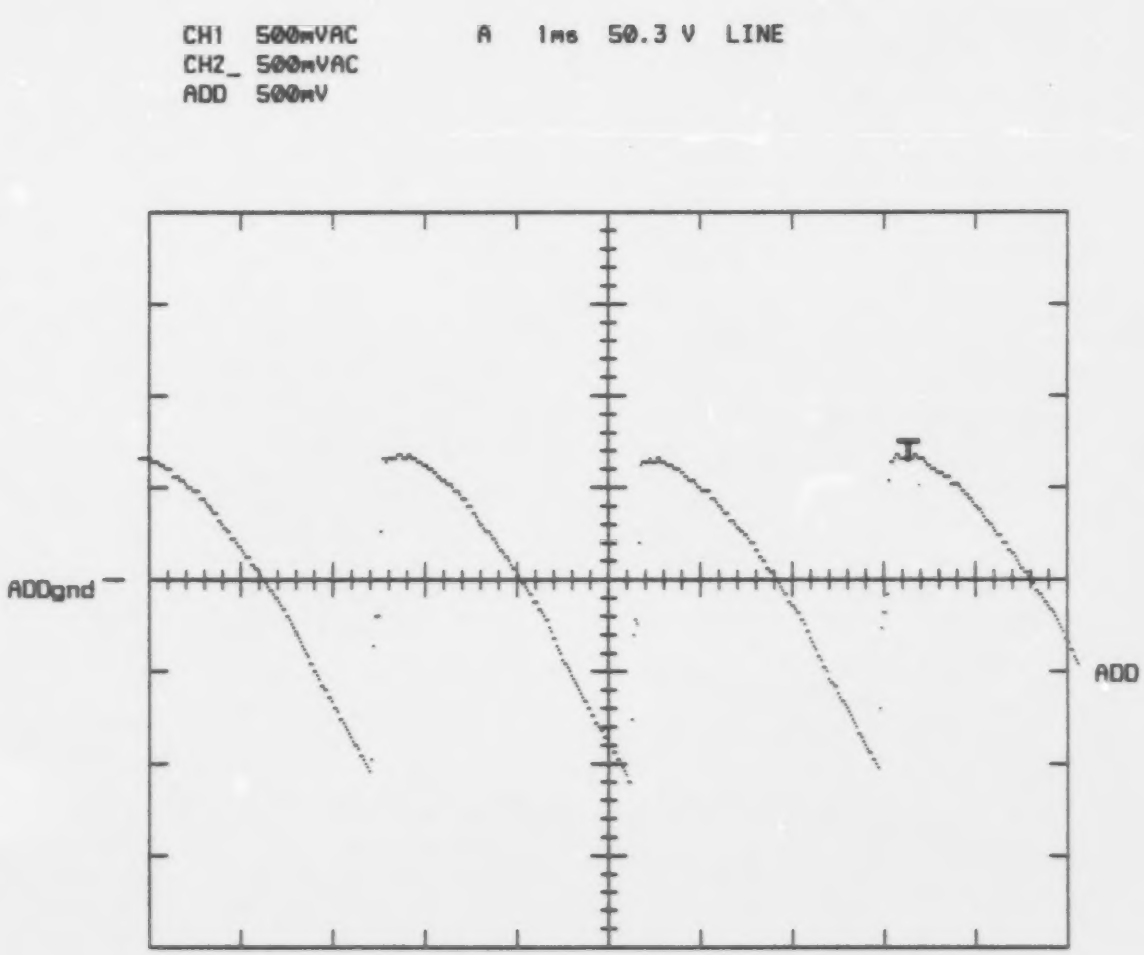


Figure A3.8 SCR voltage @ 250 A. (1V:-100V)

channel 2: cathode
channel 1: anode

CH1 1V A 1ms 50.3 V LINE
CH2_ 1V

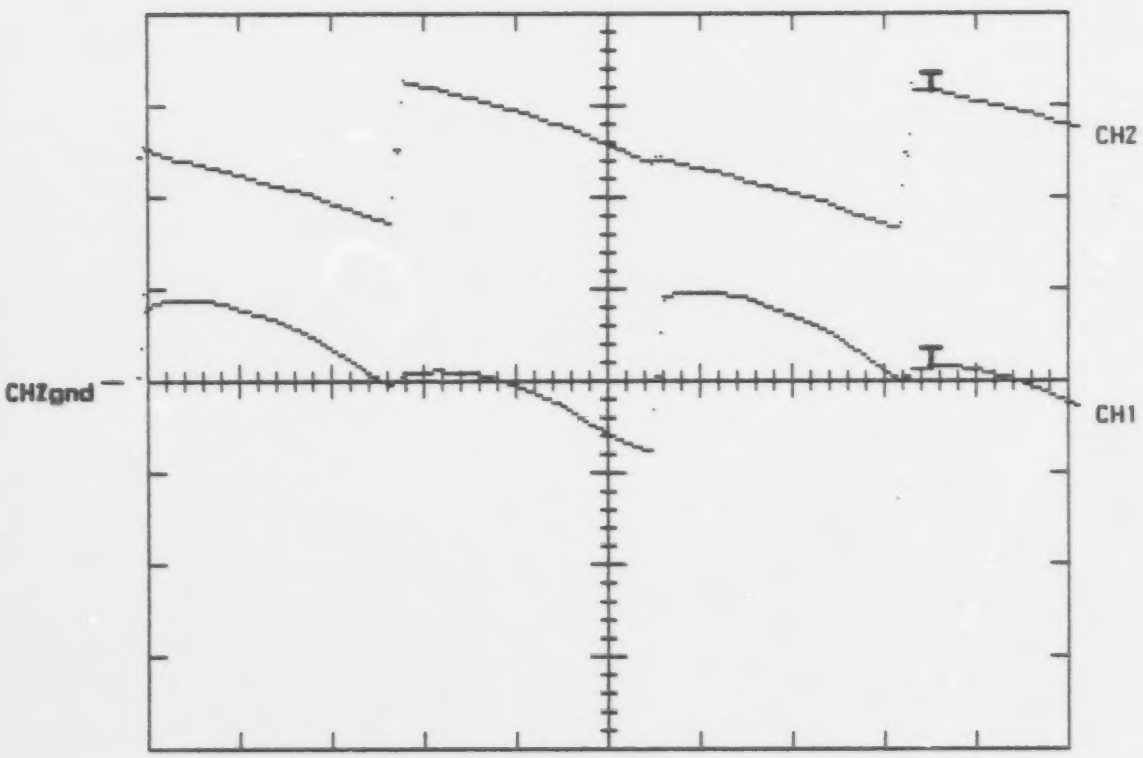


Figure A3.9 SCR voltage @ 300 A. (1V:-100V)

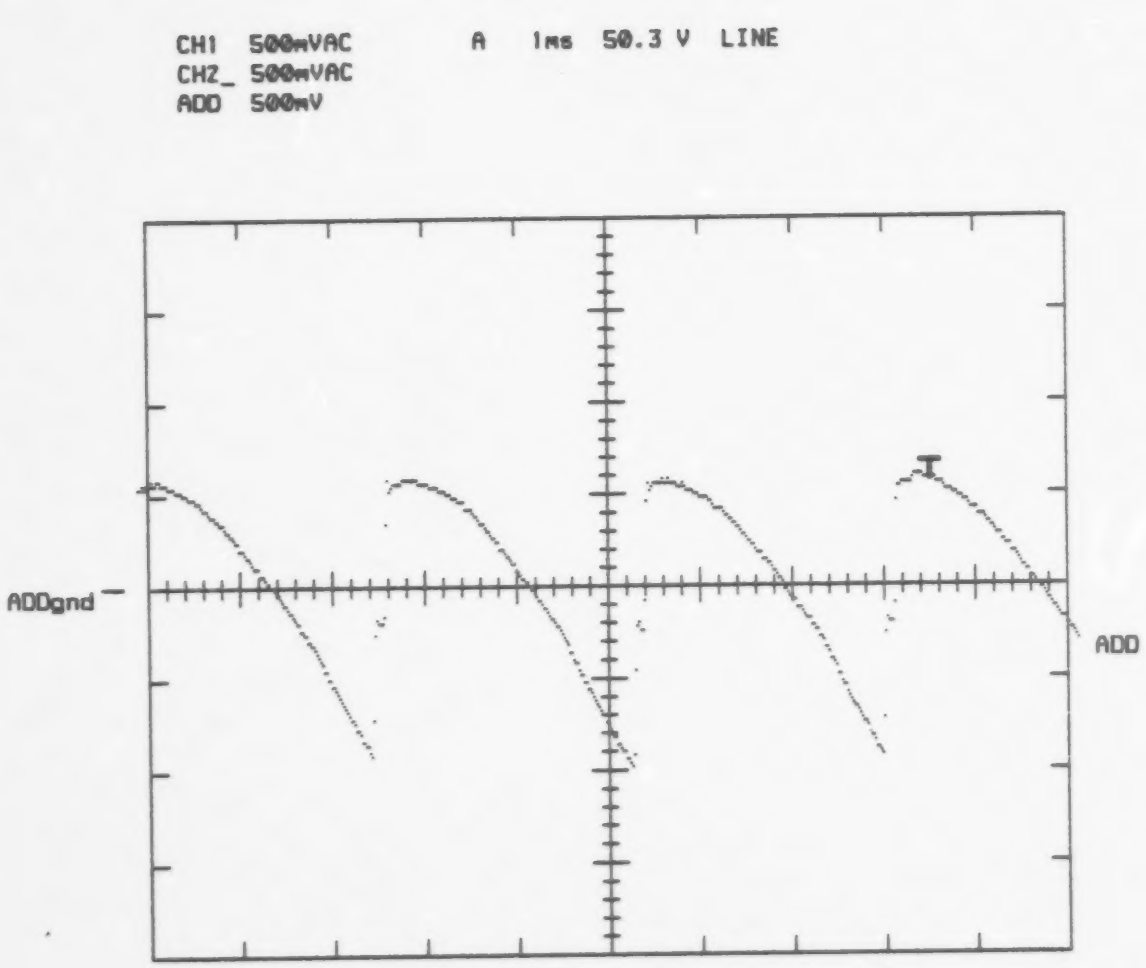


Figure A3.10 SCR voltage @ 300 A. (1V:-100V)

channel 2: cathode
channel 1: anode

CH1 1V A 1ms 50.3 V LINE
CH2_ 1V

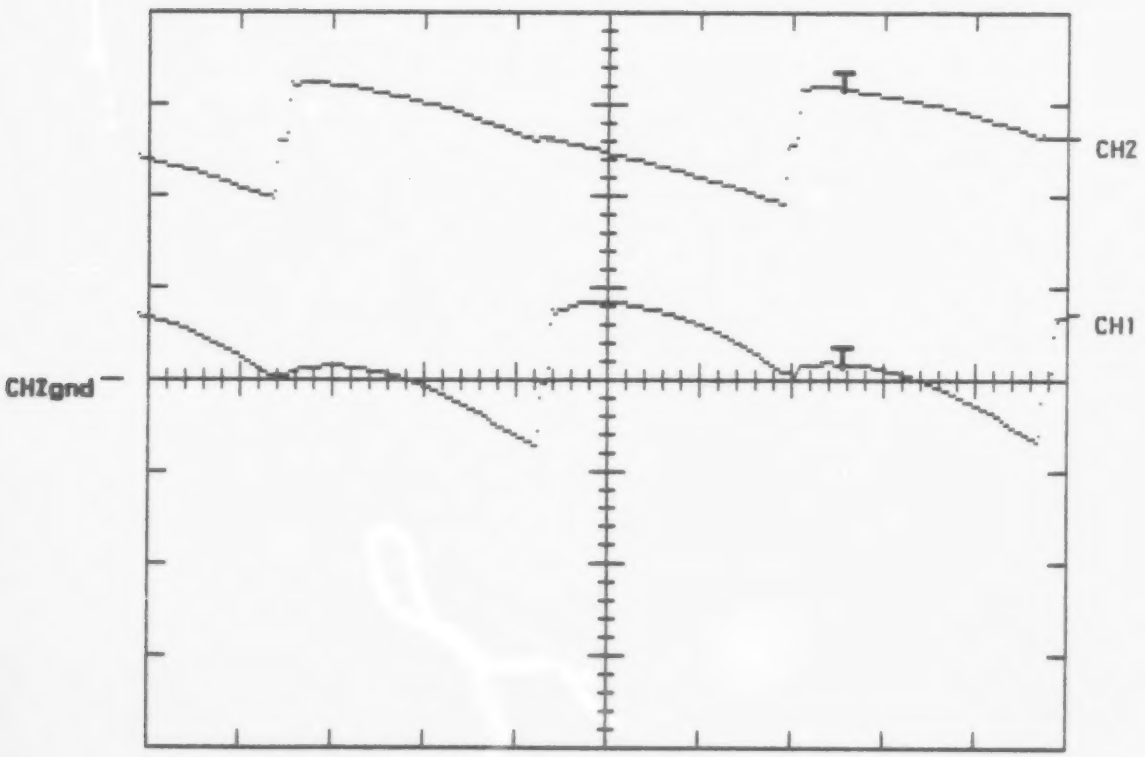


Figure A3.11 SCR voltage @ 350 A. (1V:-100V)

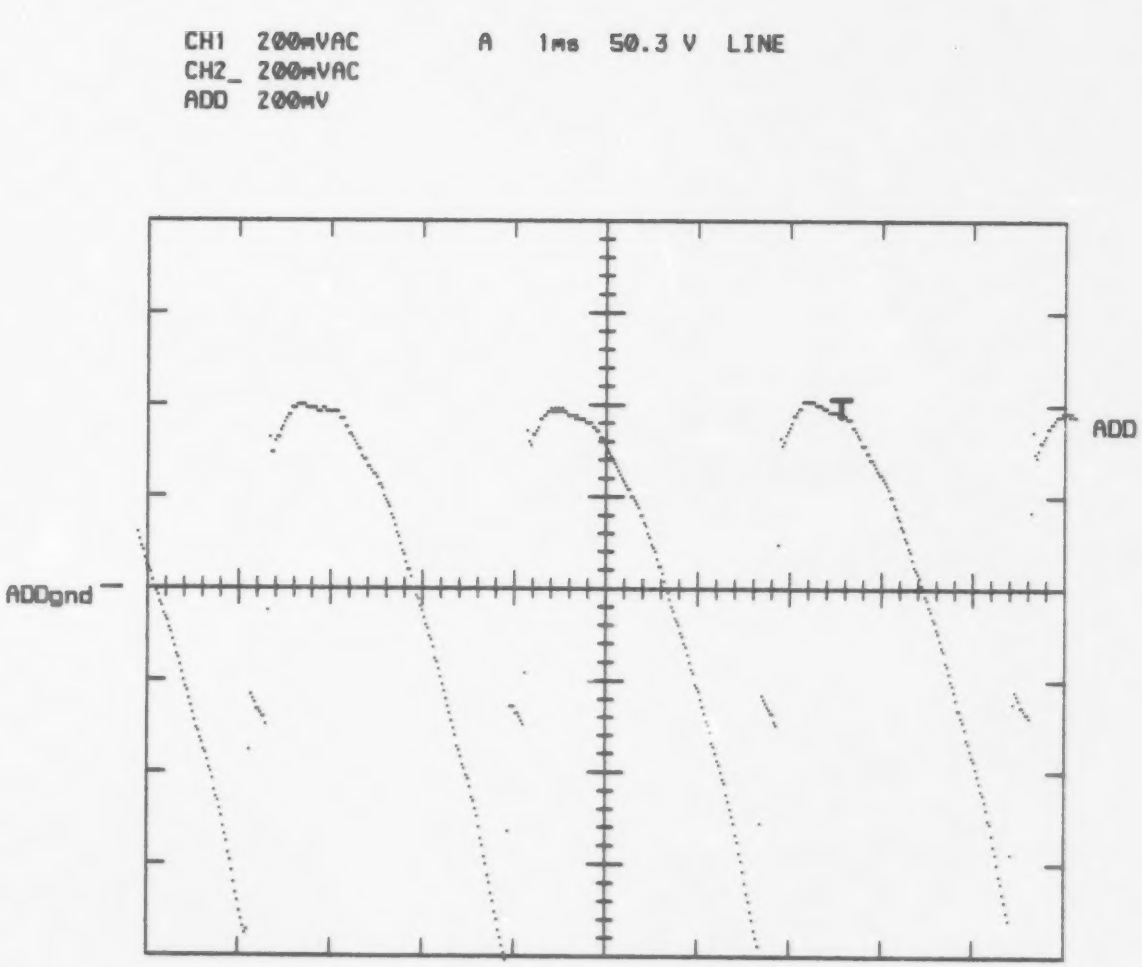


Figure A3.12 SCR voltage @ 350 A. (1V:-100V)

CH1 500mVAC A 1ms 50.3 V LINE
CH2_ 500mVAC
ADD 500mV

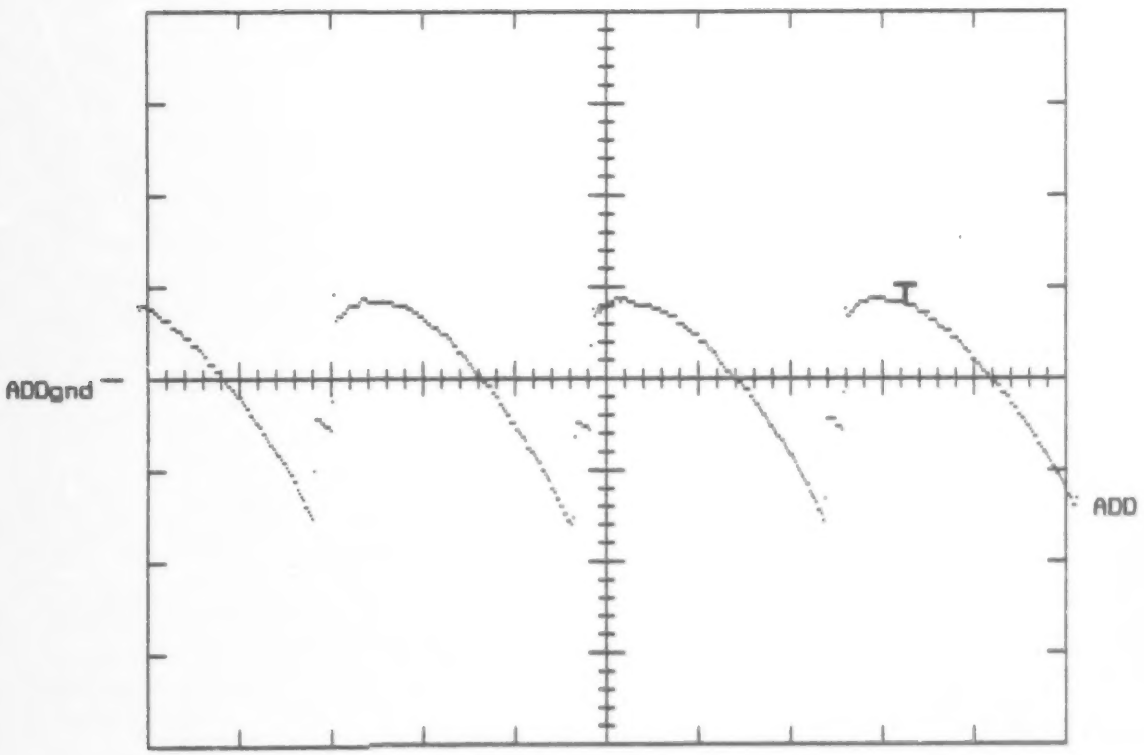


Figure A3.13 SCR voltage @ 350 A. (1V:-100V)

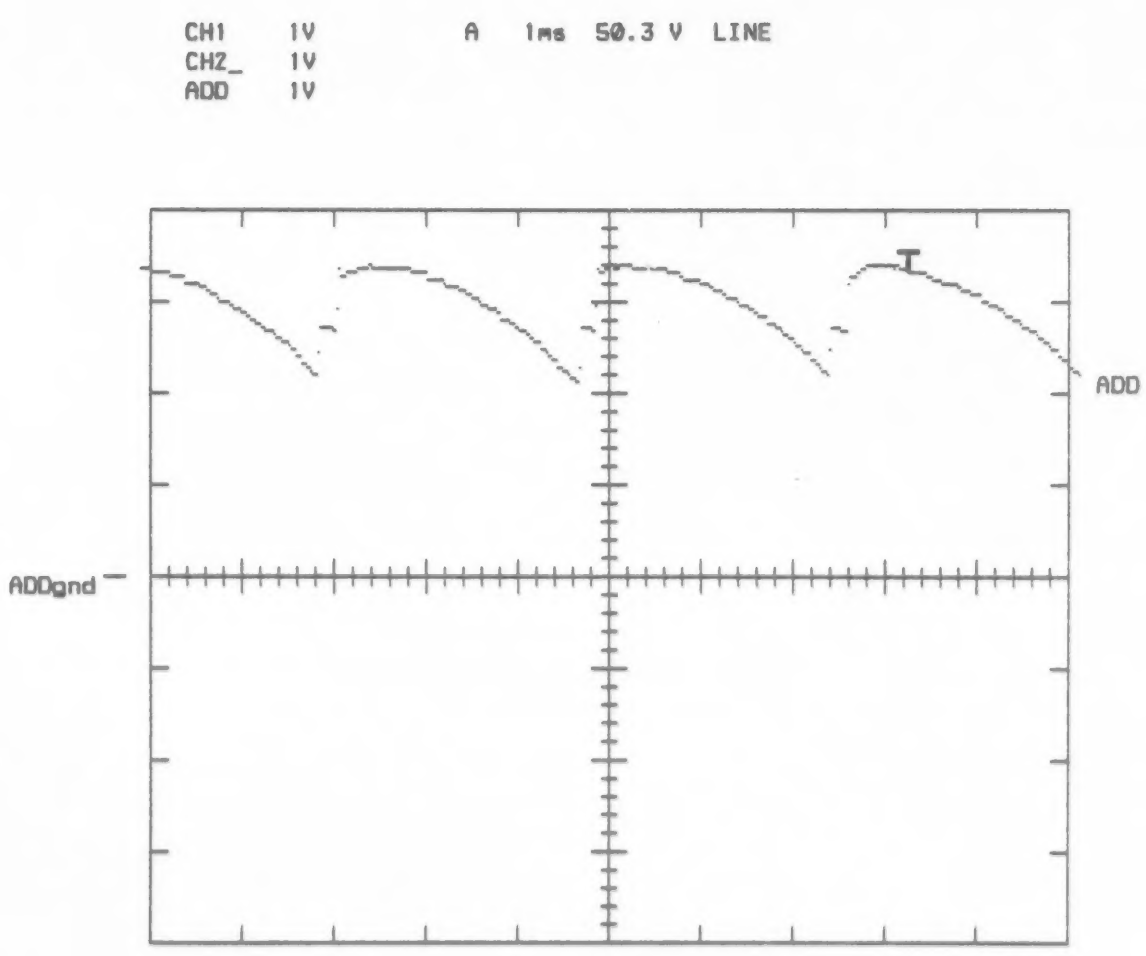
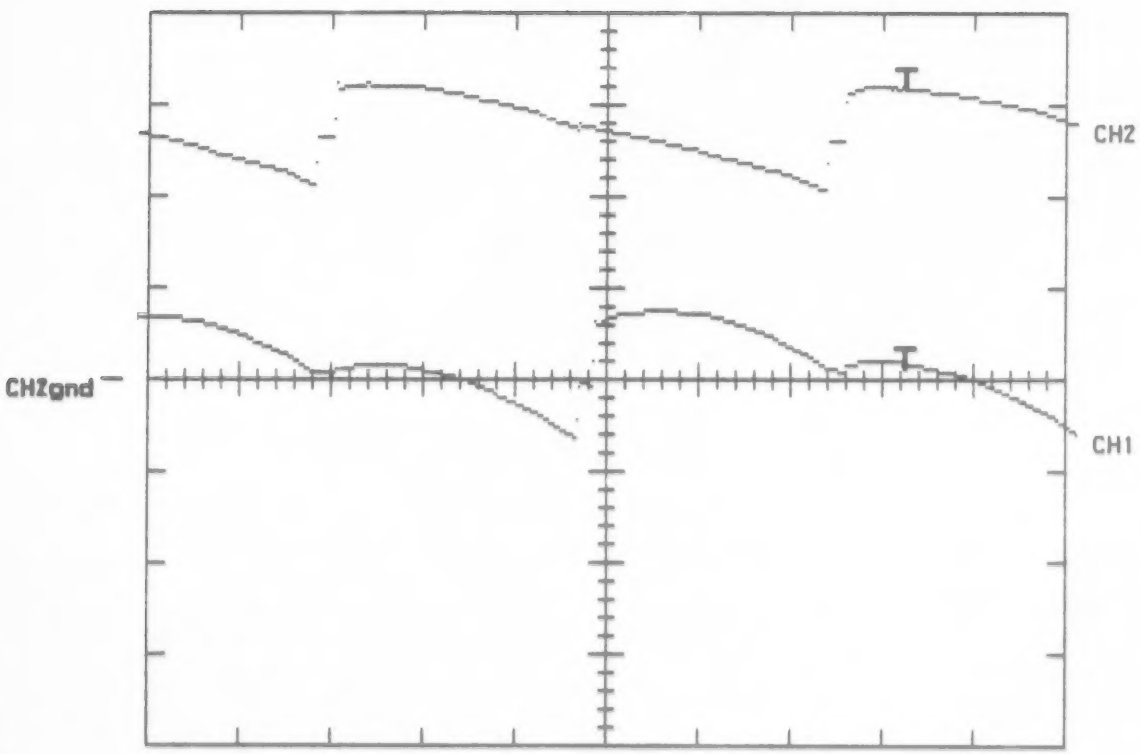


Figure A3.14 SCR voltage @ 350 A. (1V:-100V)

channel 2: cathode
channel 1: anode

CH1 1V A 1ms 50.3 V LINE
CH2_ 1V



APPENDIX A

Table A4: Summary of Measured Data - Arc Voltage

Arc Current (A)	Max (-V)	Min (-V)	Avg. (-V)	% Ripple	Bottom Peak to 'T' (ms)	Figure #
100	234	154	216	39.1	2.27	A4.1
150	250	192	241	26.1	2.47	A4.3
200	264	224	261	17.2	2.88	A4.5
250	275	240	264	13.8	3.02	A4.7
300	290	259	276	10.3	3.245	A4.9
350	300	284	295	9.5	3.645 - 3.440	A4.11

Figure A4.1 Arc voltage @ 100 A. (1V:-100V)

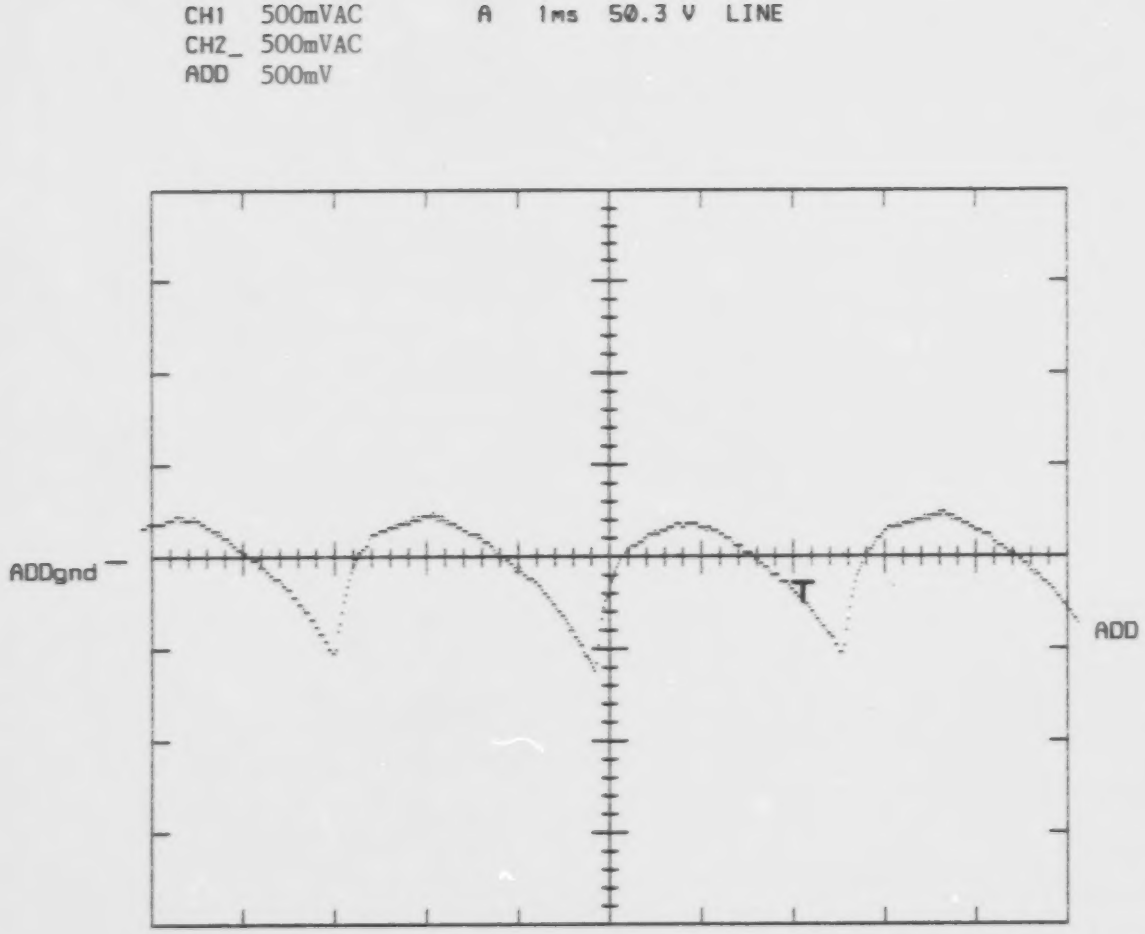


Figure A4.2 Arc voltage @ 100 A. (1V:-100V)

channel 2: cathode
channel 1: anode

CH1 1V A 1ms 50.3 V LINE
CH2_ 1V

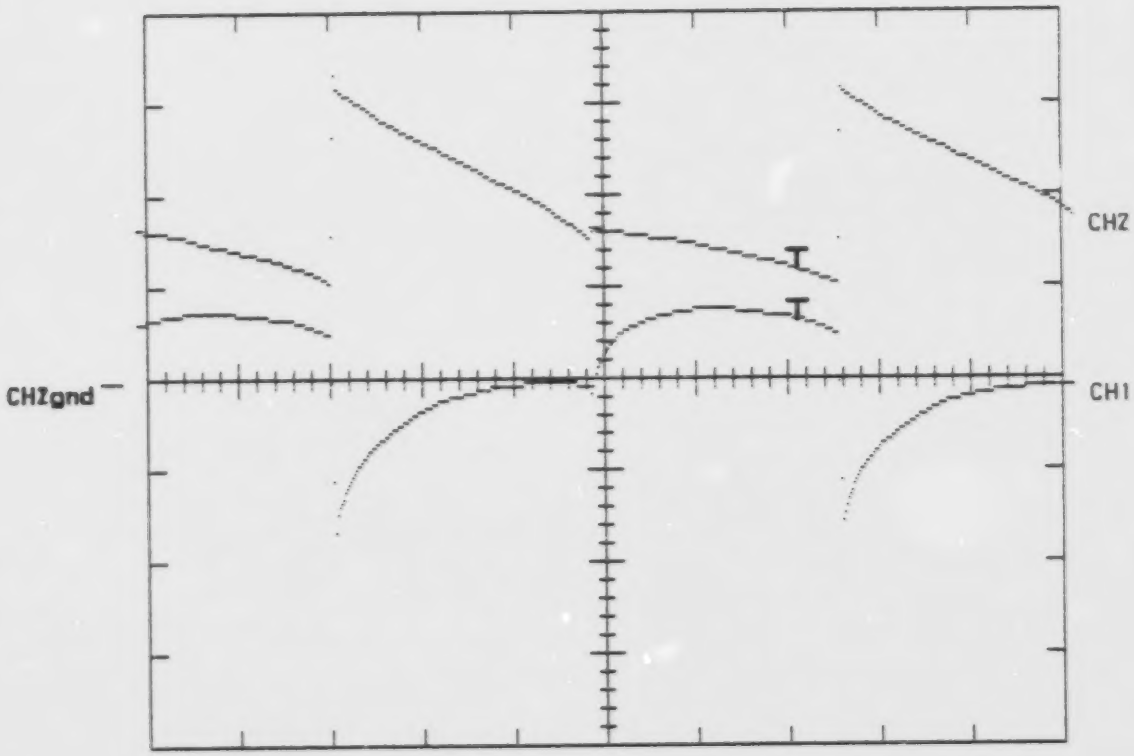


Figure A4.3 Arc voltage @ 150 A. (1V:-100V)

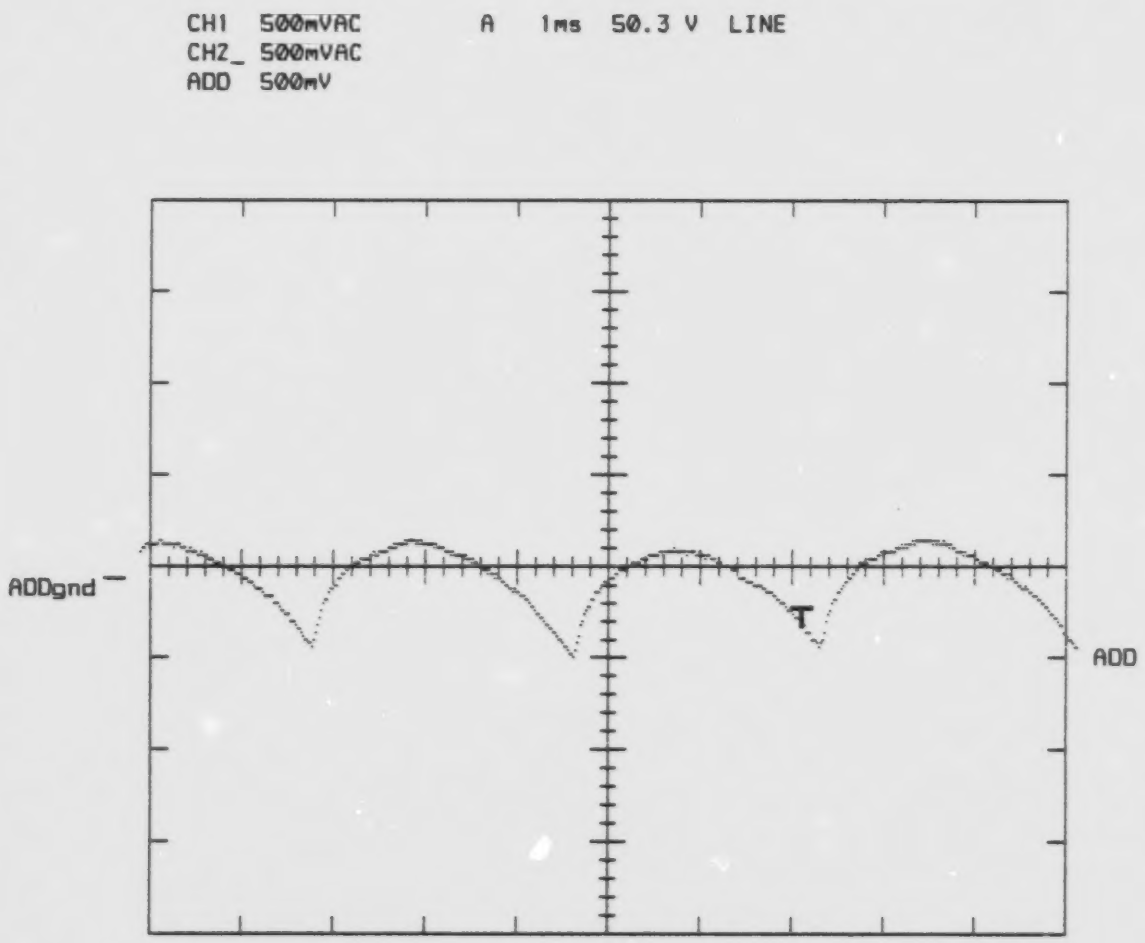


Figure A4.4 Arc voltage @ 150 A. (1V:-100V)

channel 2: cathode
channel 1: anode

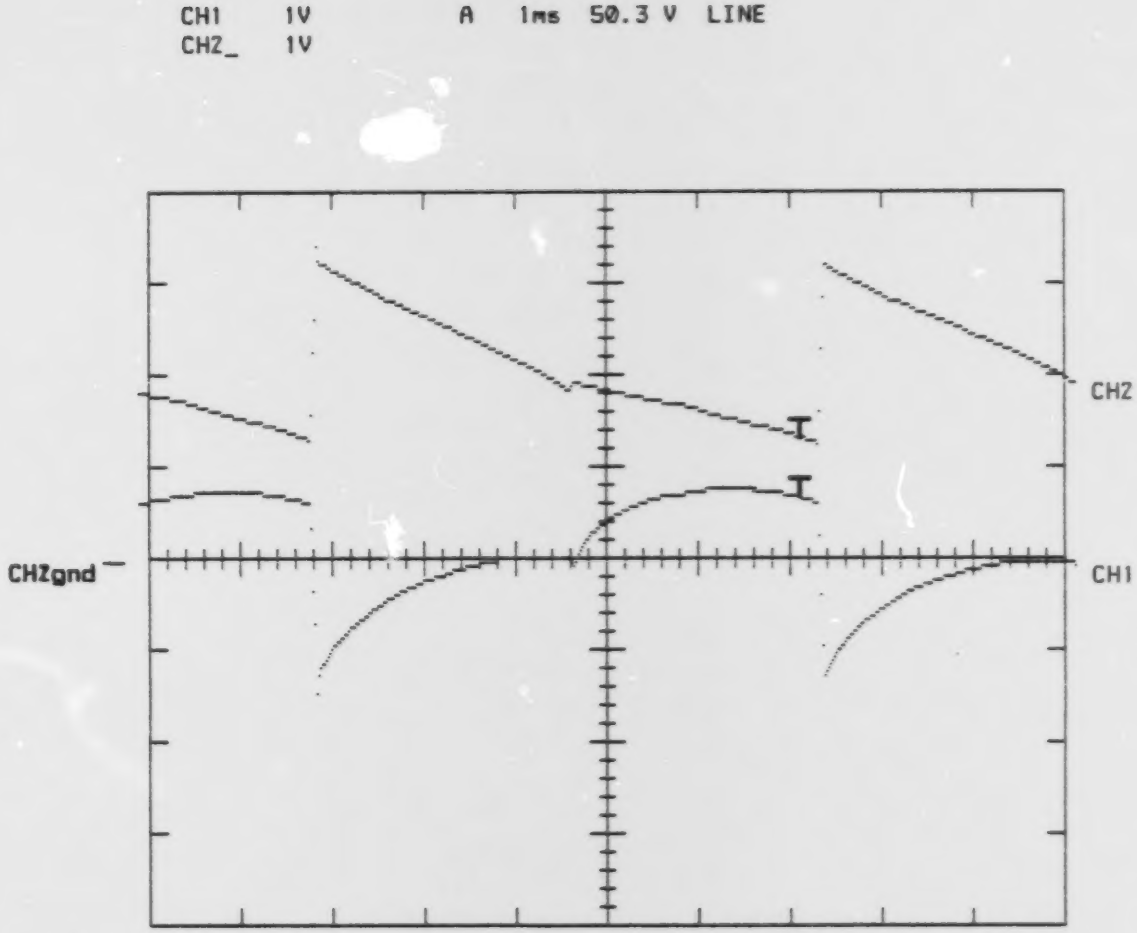


Figure A4.5 Arc voltage @ 200 A. (IV:-100)

CH1 500mVAC A 1ms 50.3 V LINE
CH2_ 500mVAC
ADD 500mV

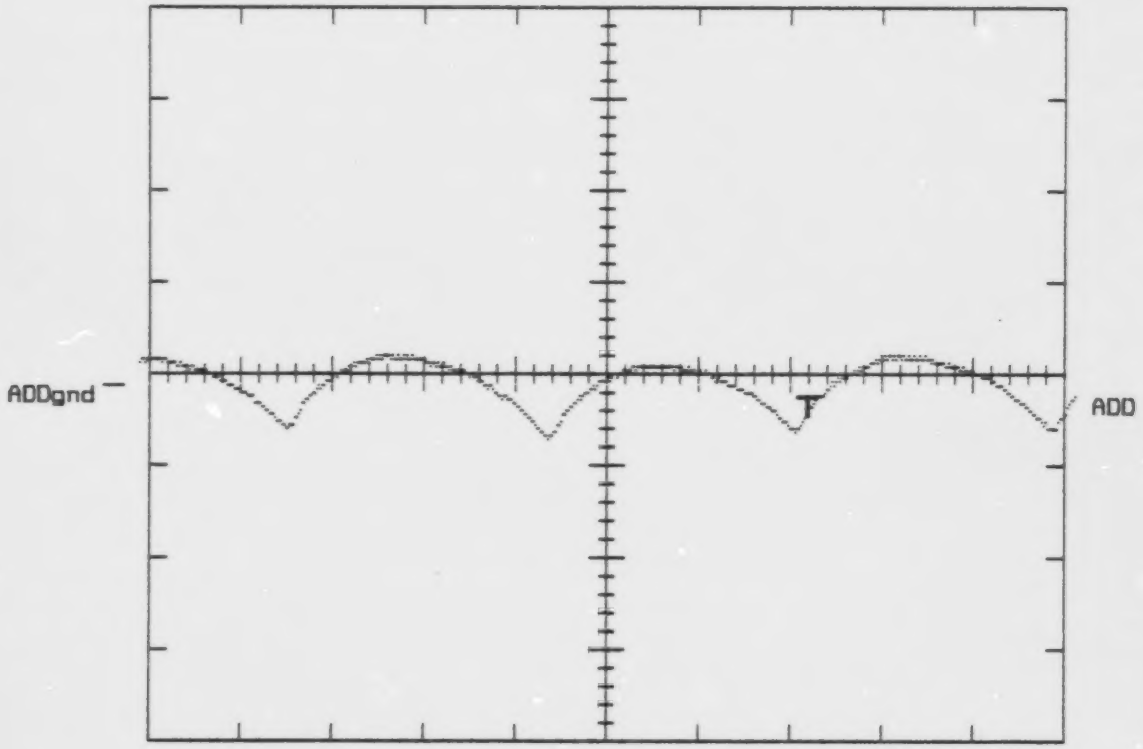


Figure A4.6 Arc voltage @ 200 A. (1V:-100V)

channel 2: cathode
channel 1: anode

CH1 1V A 1ms 50.3 V LINE
CH2_ 1V

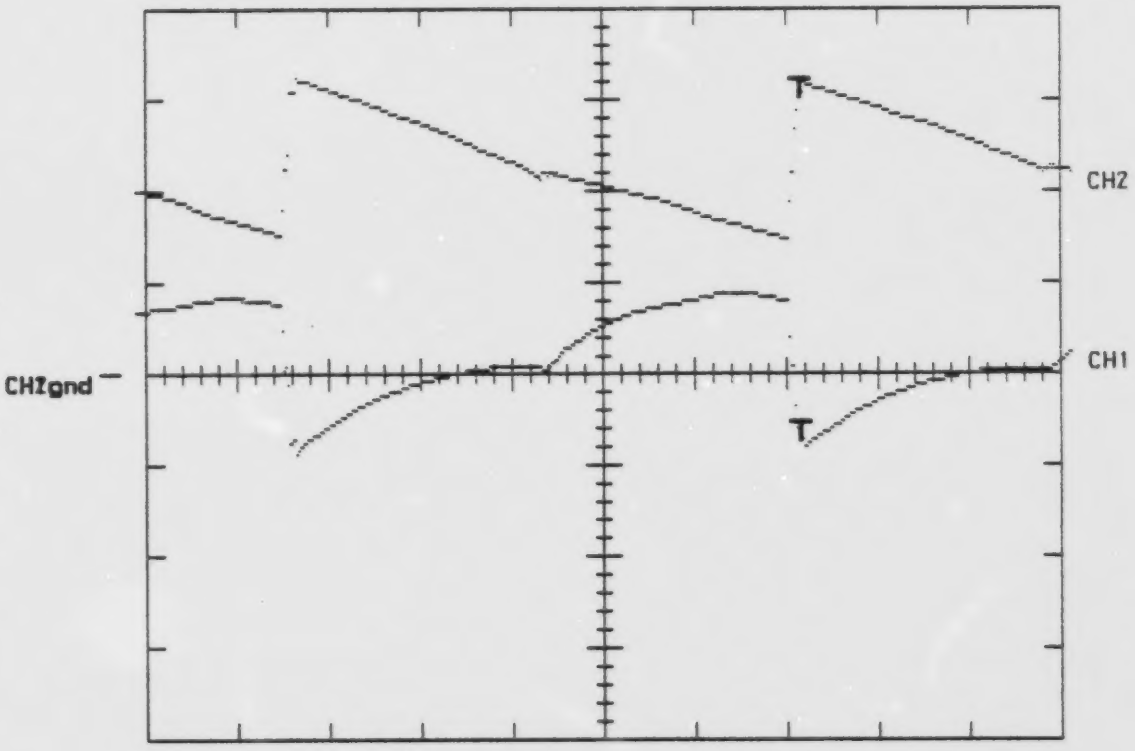


Figure A4.7 Arc voltage @ 250 A. (1V:-100V)

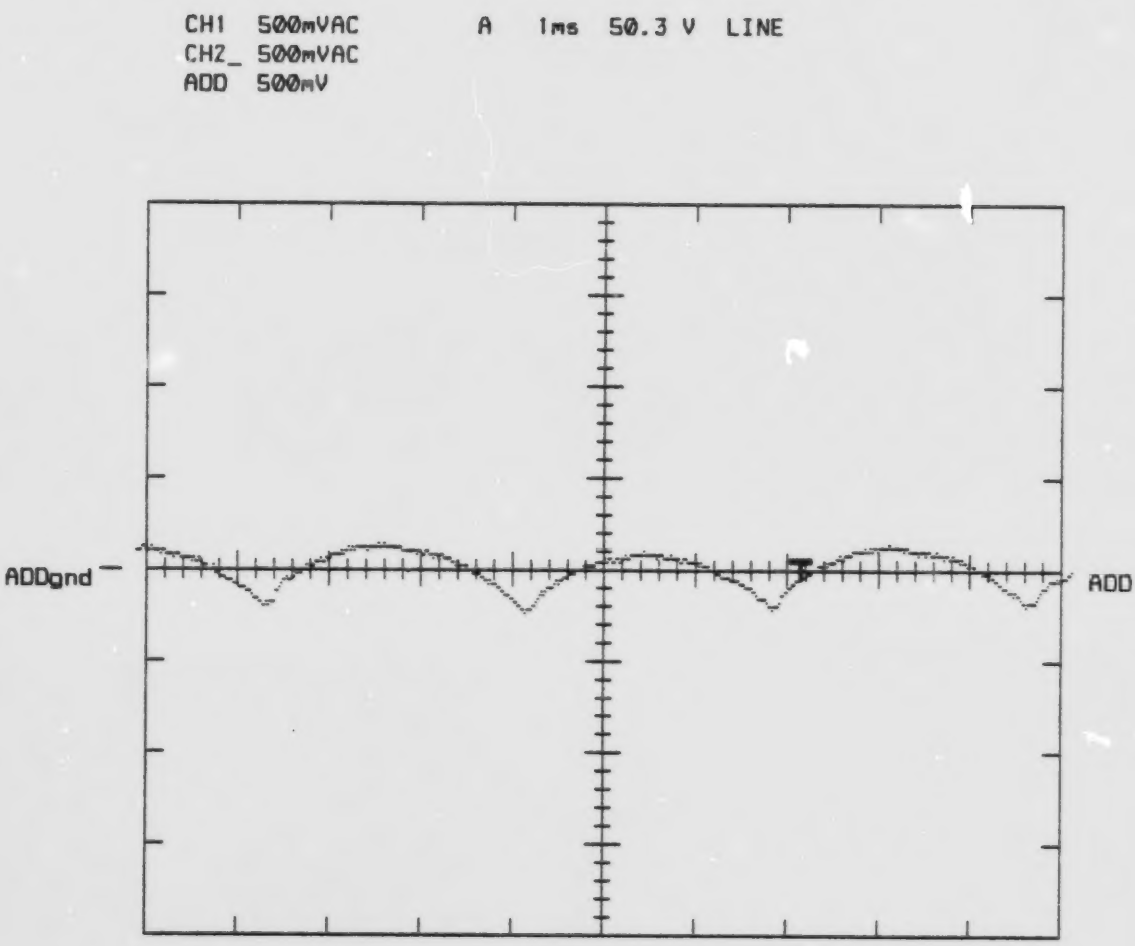


Figure A4.8 Arc voltage @ 250 A. (1V:-100)

channel 2: cathode
channel 1: anode

CH1 1V A 1ms 50.3 V LINE
CH2_ 1V

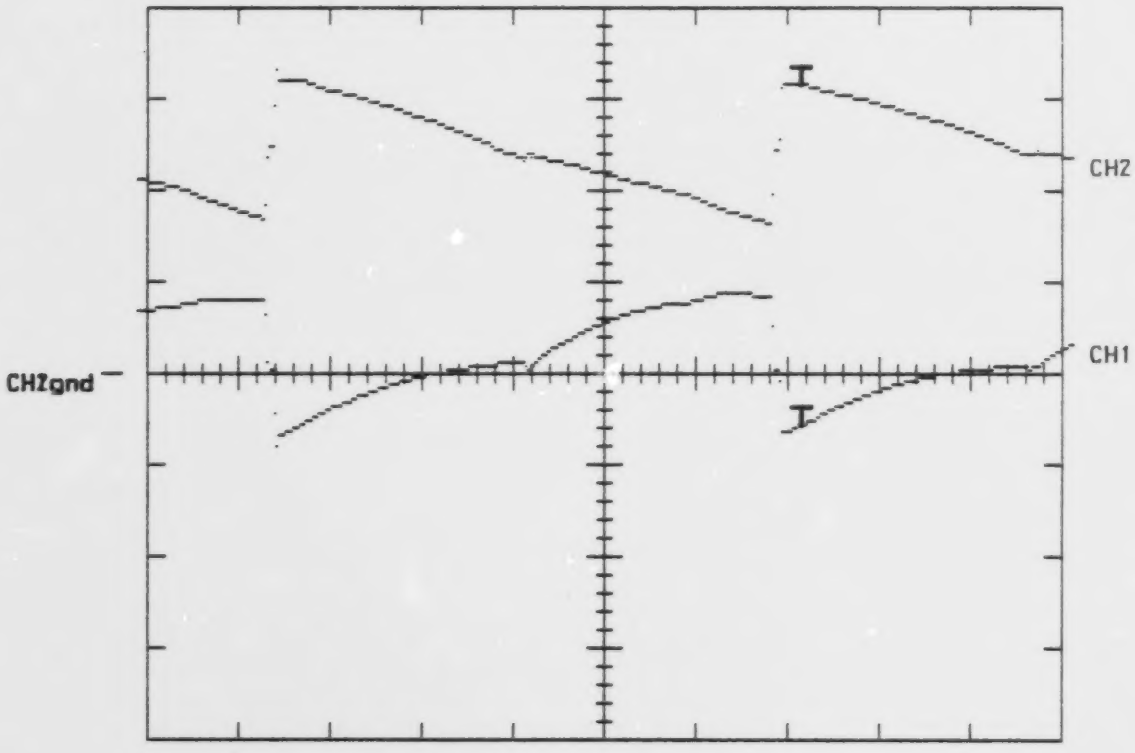


Figure A4.9 Arc voltage @ 300 A. (1V:-100V)

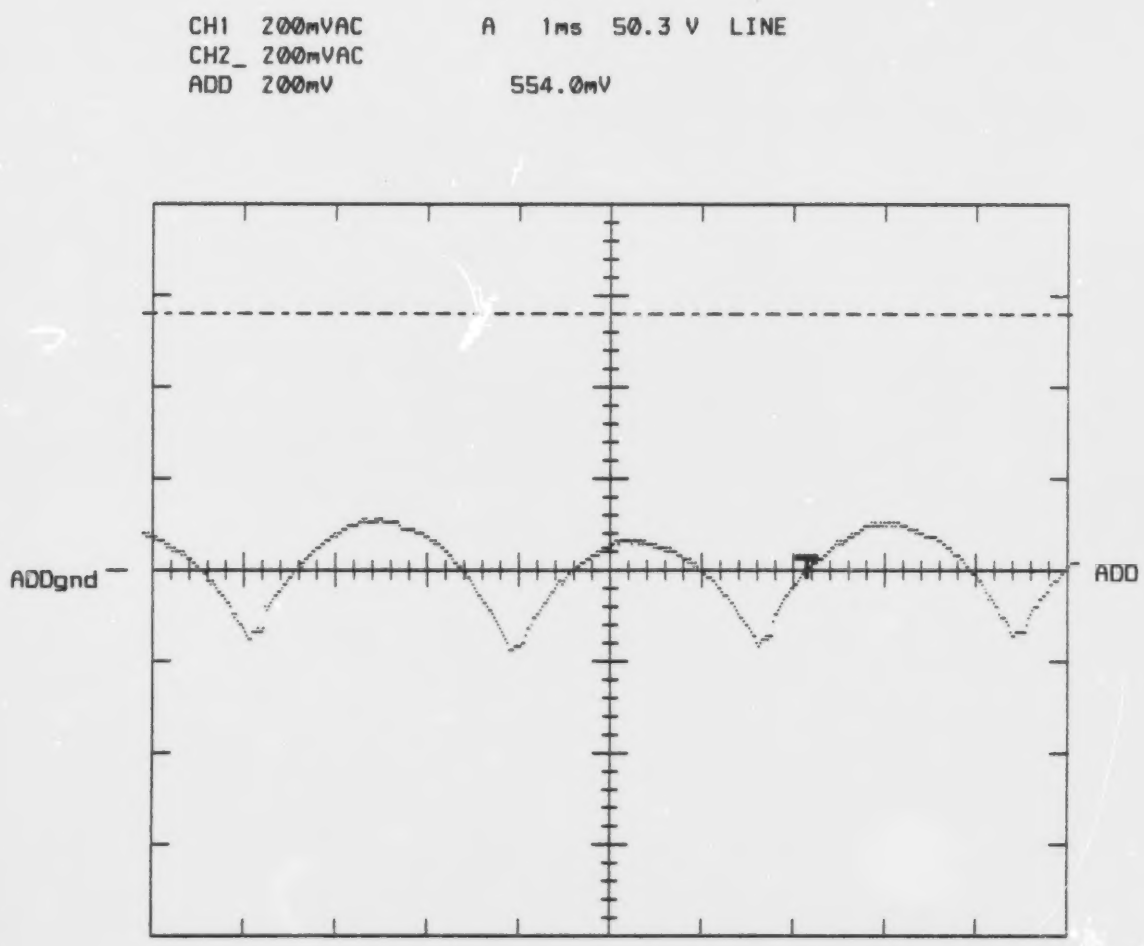


Figure A4.10 Arc voltage @ 300 A. (1V:-100V)

channel 2: cathode
channel 1: anode

CH1 1V A 1ms 50.3 V LINE
CH2_ 1V

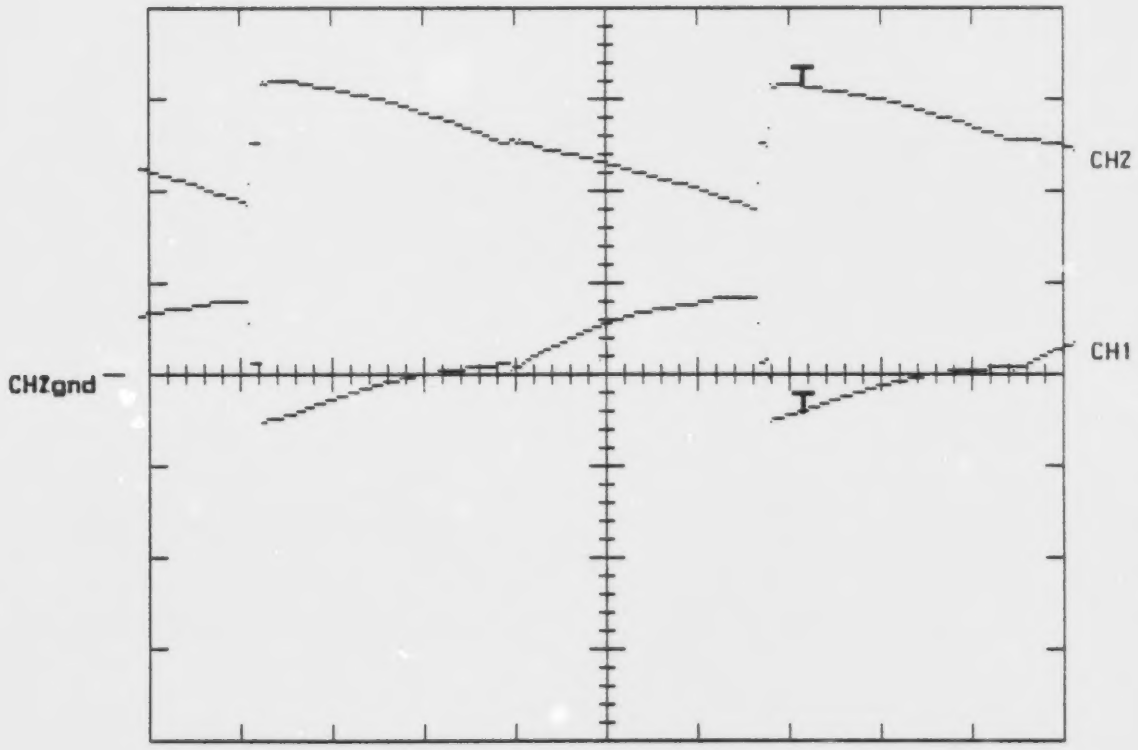


Figure A4.11 Arc voltage @ 350 A. (1V:-100V)

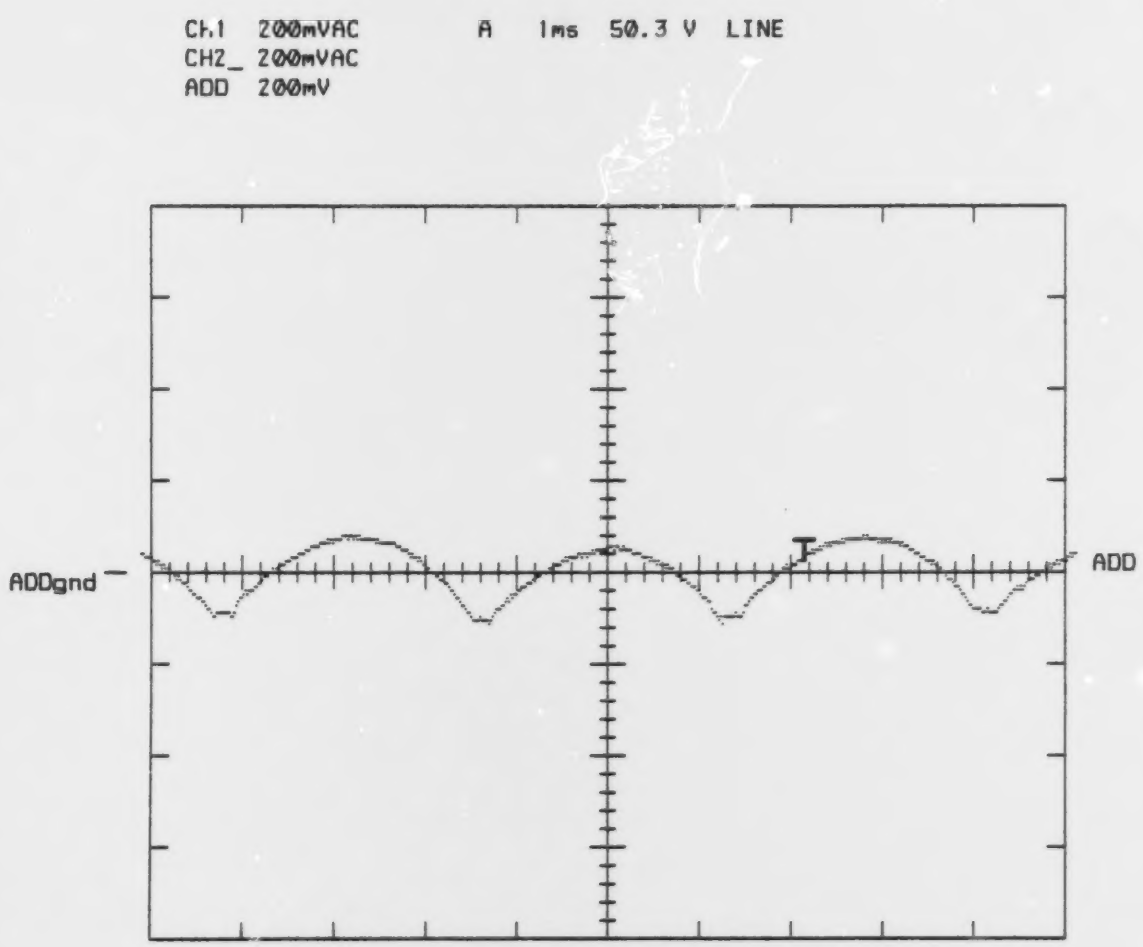


Figure A4.12 Arc voltage @ 350 A. (1V:-100V)

channel 2: cathode
channel 1: anode

CH1 1V A 1ms 50.3 V LINE
CH2_ 1V

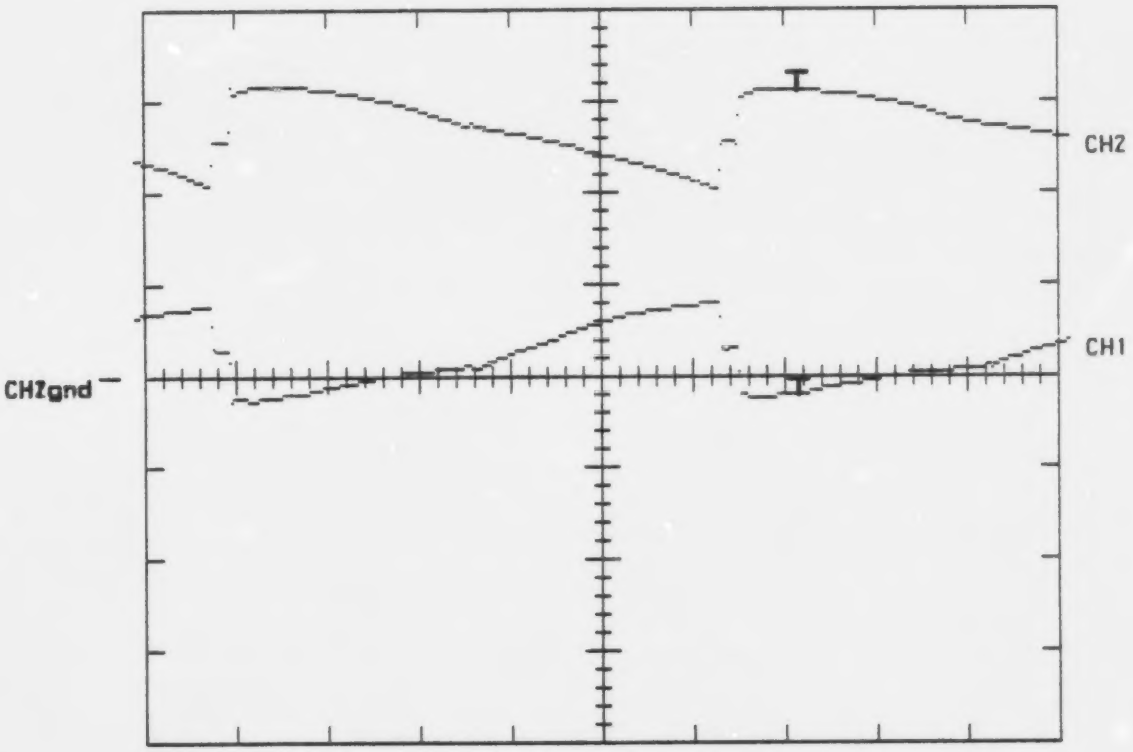


Table A5: Summary of Measured Data - AC Mains

Figure A5.2 677 V p-p (239.4 Vr.m.s.)

First Zero Crossing to 'T' = 10.055 ms
Second Zero Crossing to 'T' = 1.685 ms

Figure A5.3: The phase voltages contain a high zero phase sequence current component which circulates in the secondary delta winding of the transformer. The phase voltages on the primary of the transformer do not contain this distortion. Due to the zero phase sequence shift in the voltage with respect to ground, the actual firing angle delay is obscured and can only be accurately derived from the SCR controller (see Figure 2).

Figure A5.1 AC mains with arc off. (1V:100V)

channel 1: blue phase to ground
channel 2: red phase to ground

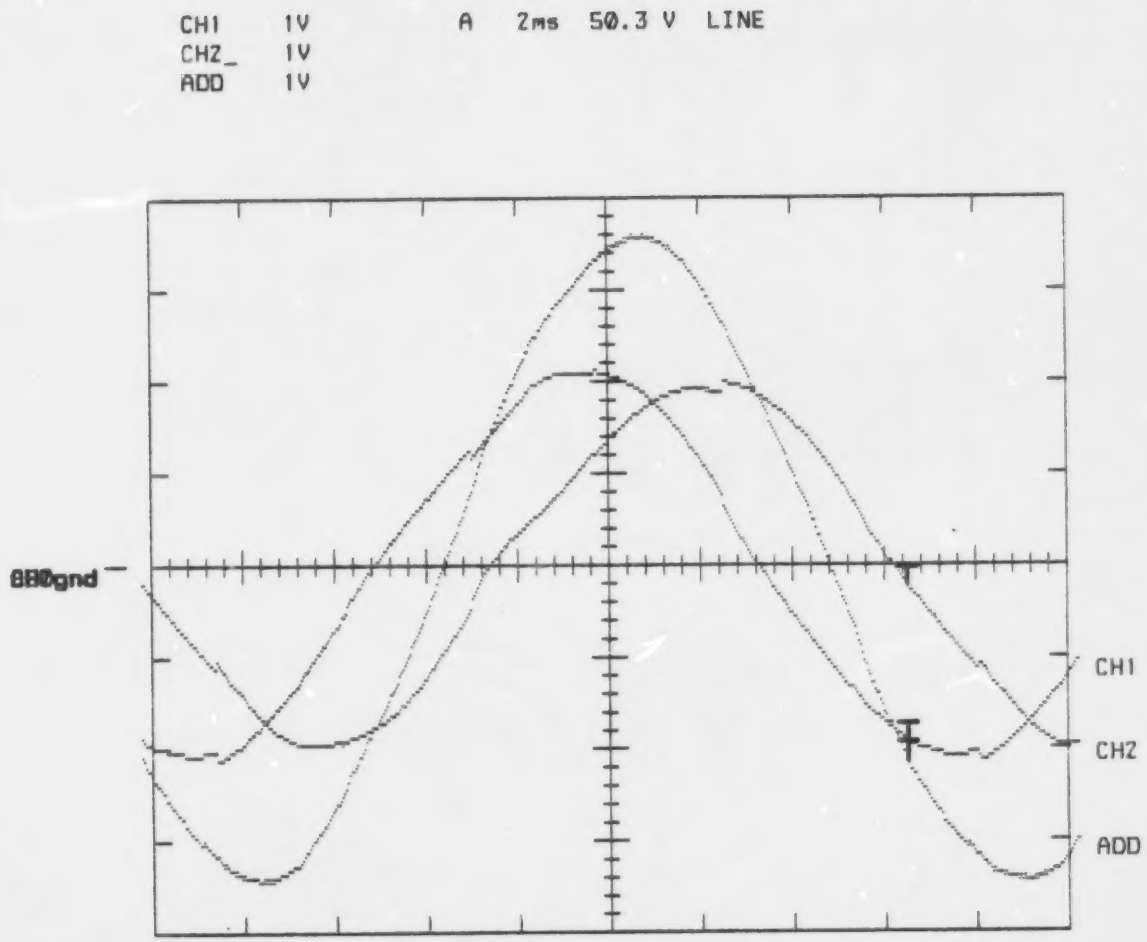


Figure A5.2 AC mains @ 300 A. (1V:100V)

channel 1: blue phase to ground
channel 2: red phase to ground

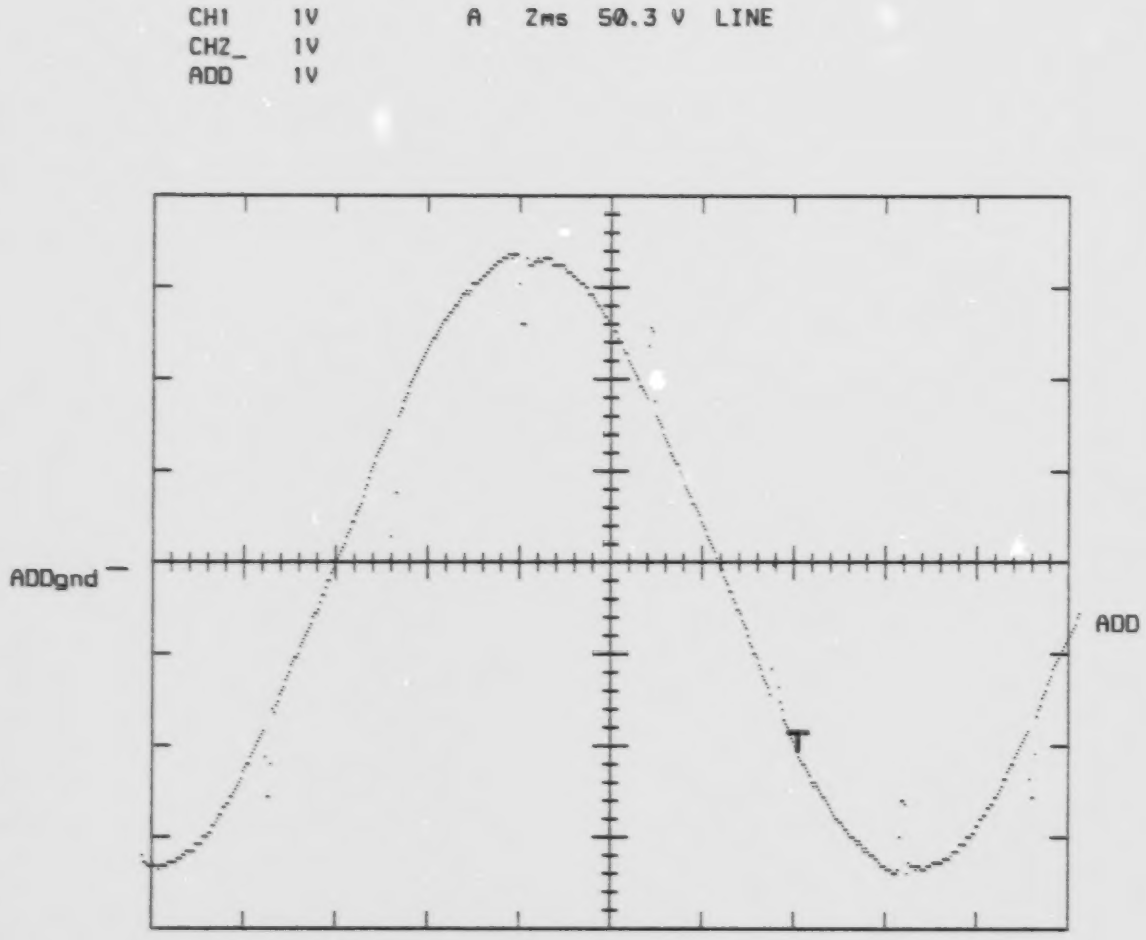
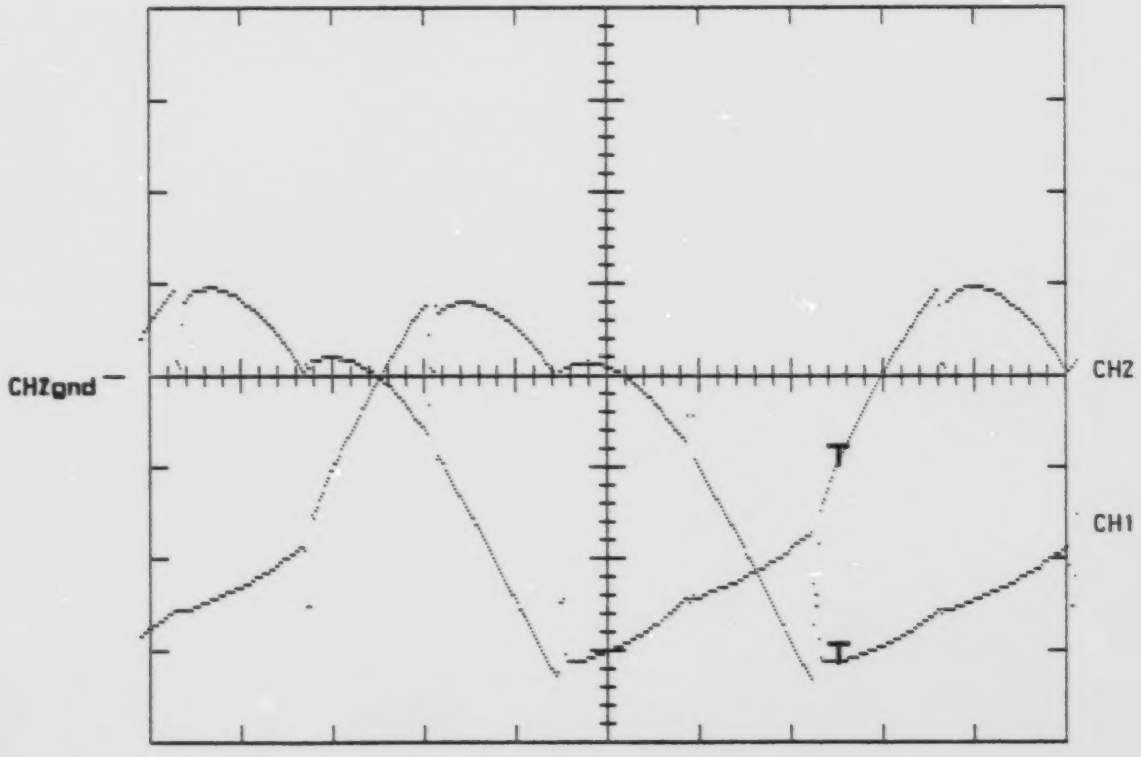


Figure A5.3 AC mains @ 300 A. (1V:100V)

channel 1: blue phase to ground
channel 2: red phase to ground

CH1 1V A 2ms 50.3 V LINE
CH2 1V



APPENDIX B

RECONSTRUCTION OF LIGHT INTENSITY WAVEFORMS FROM THE FREQUENCY SPECTRUM DATA

APPENDIX B

As the phase information of the frequency spectrum was unattainable, some simple intuitive assumptions were made based on the general effects of the phase positioning of the multiple harmonics. Two major features of the original waveform are the narrow minima and the small variation in the minima's amplitude in comparison with the large variations for the maxima. To achieve the narrowest possible minima, the Fourier series would be the summation of $(-a_{n360})\cos(n_{360}*\text{angle})$. To minimize the amplitude variation of the minima, the Fourier series of the 60 Hz harmonics (i.e. 60, 120, 240, 480, 600) would be the summation of $(-a_{n60})\sin(n_{60}*\text{angle})$. The data used to reconstruct the waveforms in Figures B1 to B3 are given in Table B1.

APPENDIX B

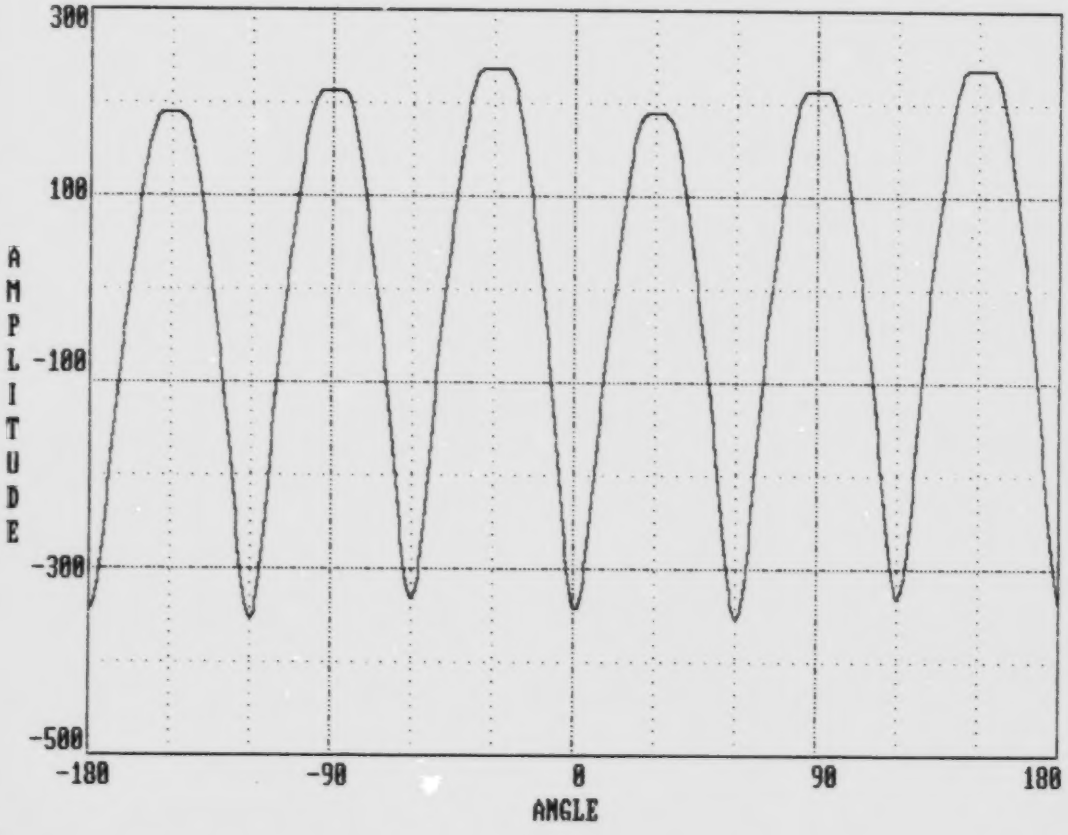


Figure B1. Reconstructed light intensity waveform at 100 Amps.

APPENDIX B

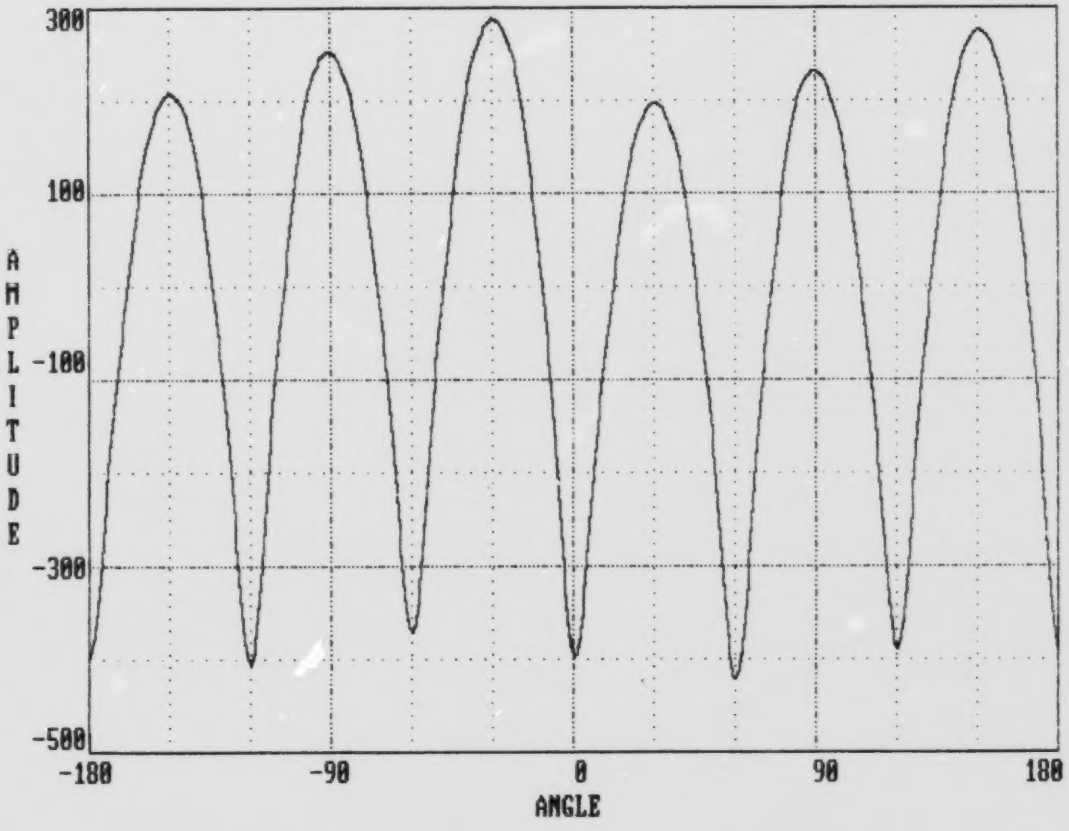


Figure B2. Reconstructed light intensity waveform at 250 Amps.

APPENDIX B

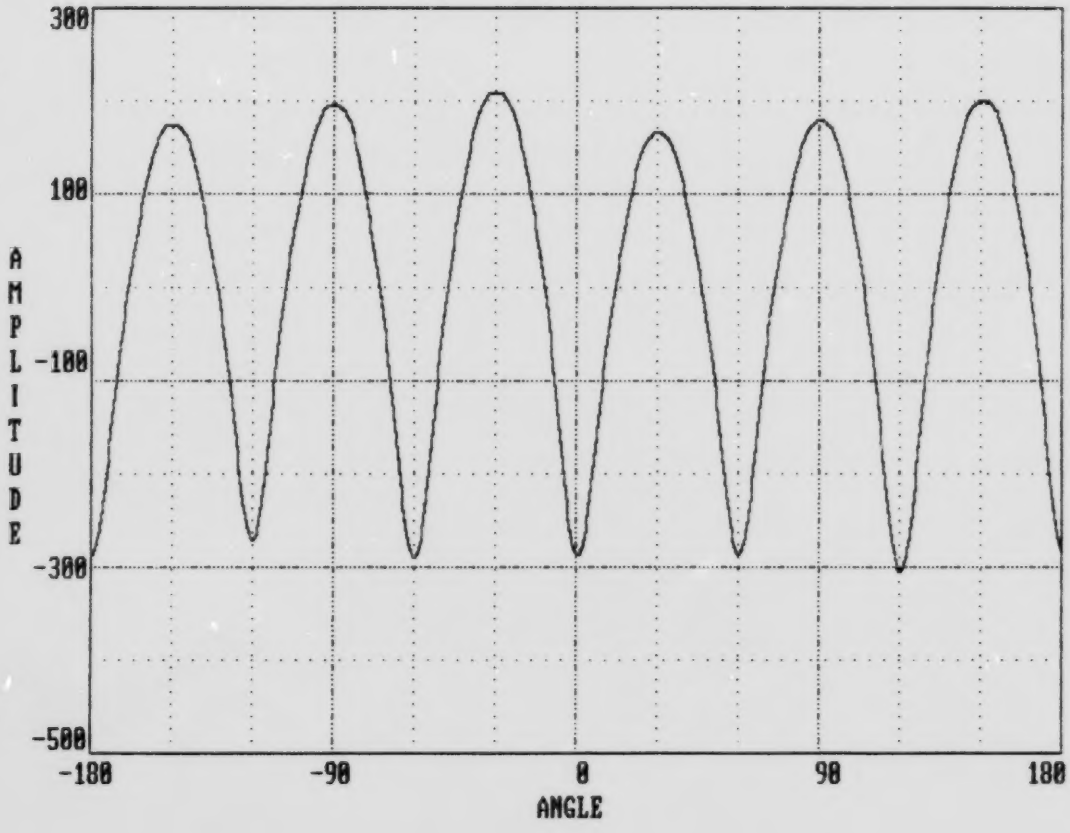


Figure B3. Reconstructed light intensity waveform at 350 Amps.

APPENDIX B

Table B1: Waveform Reconstruction Data

Frequency (Hz)	100A (mV)	250A (mV)	350A (mV)	Phase Relation	*Harmonic Reduction Multiplier	**Sub-Harmonic Reduction Multiplier
60		10.4	9.0	-sin(θ)	0.2134	0.05
120	25.6	32.6	8.7	-sin(2θ)	0.2119	0.05
240	14.6	19.9	15.6	-sin(4θ)	0.6582	0.05
360	264.0	289.0	220.9	-cos(6θ)	0.00221	***
480	7.4	6.9	-	-sin(8θ)	0.00759	0.05
600	5.8	-	4.5	-sin(10θ)	0.41769	0.05
720	52.9	63.0	44.3	-cos(12θ)	0.00110	***
1080	13.3	23.6	16.6	-cos(18θ)	0.04762	***
1440	13.3	15.4	7.4	-cos(24θ)	0.05464	
1800		6.5		-cos(30θ)	0.05747	

Notes: *Values can be obtained from Figure 3 where (I_{RA}/I_O)

**Assumed reduction factor when phase-lock-loop circuit is used

***Phase-lock-loop circuit will also reduce its contributing amplitude to 5% but as its contribution is relatively small, no reduction contribution was assumed.

APPENDIX B

The reconstructed waveforms, given in Figures B1 to B3 for 100A, 250A and 350A respectively, are quite similar in shape to those in Figures of Appendix A1. The peak-to-peak values of the original waveform and the reconstructed wave are surprisingly close for the assumed set of phase relations as seen in Table B2.

By changing the firing circuit of the SCR's to phase-lock-loop control, the 60 Hz harmonics (i.e. 60, 120, 240, 480, 600 Hz) will be reduced to less than 5% of their original amplitudes. Due to the large 360 and 720 Hz amplitudes, the use of a phase-lock firing circuit will reduce the ripple's peak-to-peak amplitude by approximately 5 to 10% as illustrated in Figures B4 to B6 and Table B2.

By implementing the designed dual trap harmonic filter the simulated waveforms using the harmonic reduction multipliers from Table B1 should theoretically appear as shown in Figures B7 to B9. This would result in a maximum ripple of less than 1% as shown in Table B2. It should be noted that this is physically impossible to achieve due to the random noise and fluctuations in the arc's light intensity as discussed in chapter 9.

APPENDIX B

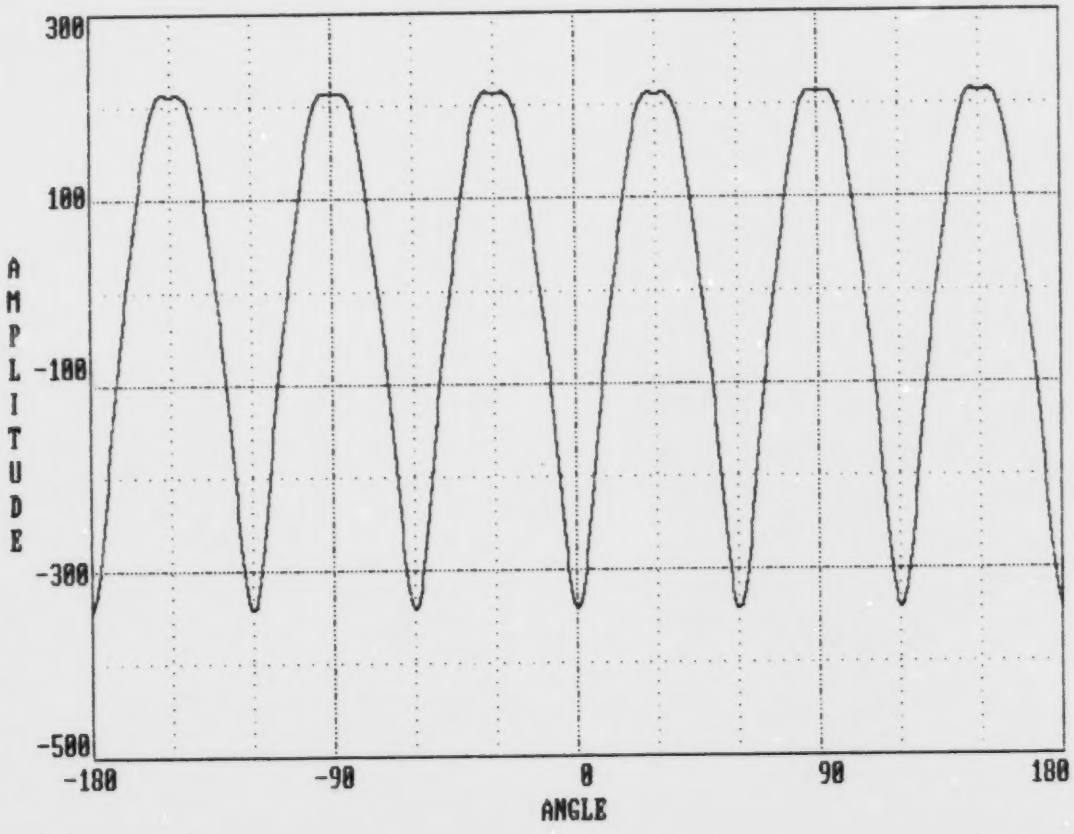


Figure B4. Simulated light intensity at 100 Amps with a phase-lock-loop SCR firing circuit.

APPENDIX B

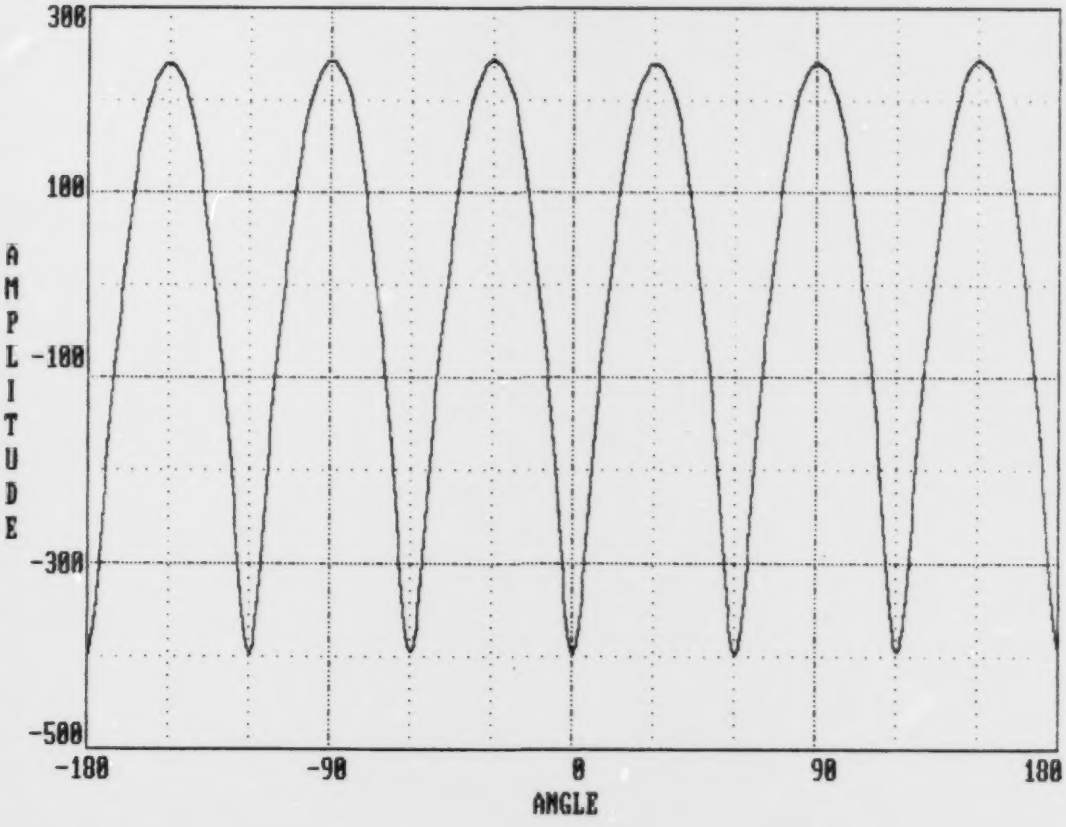


Figure B5. Simulated light intensity at 250 Amps with a phase-lock-loop SCR firing circuit.

APPENDIX B

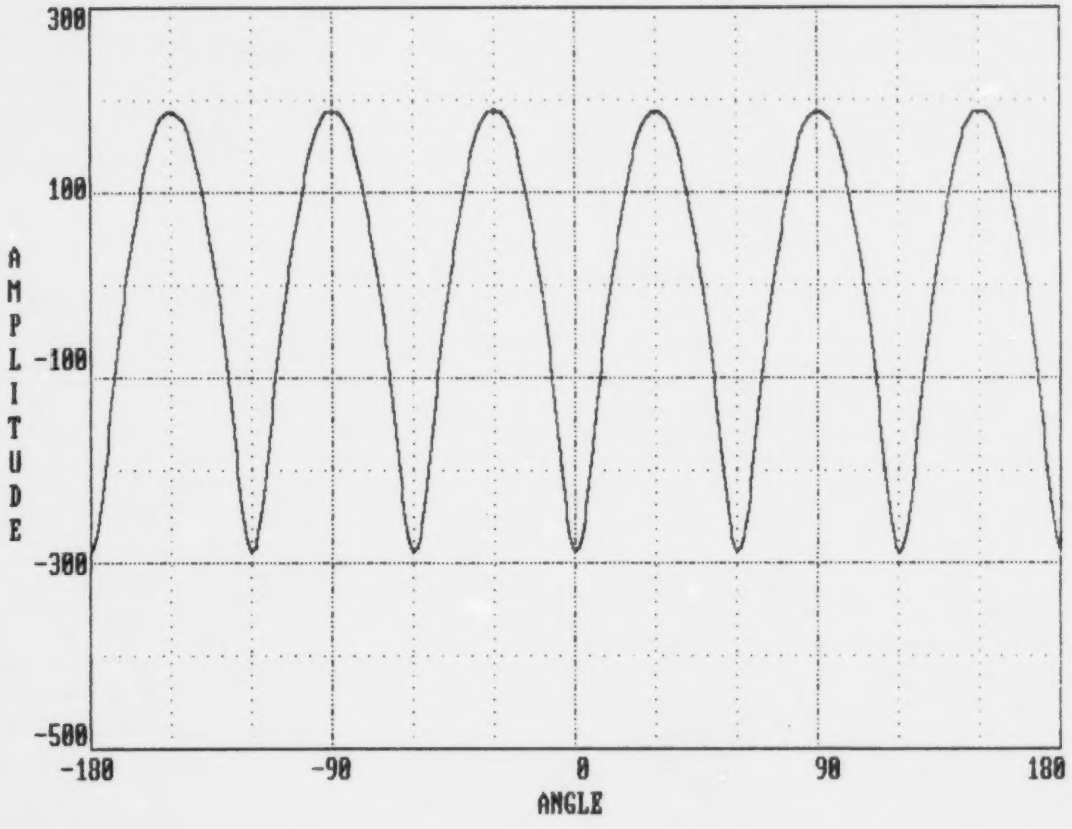


Figure B6. Simulated light intensity at 350 Amps with a phase-lock-loop SCR firing circuit.

APPENDIX B

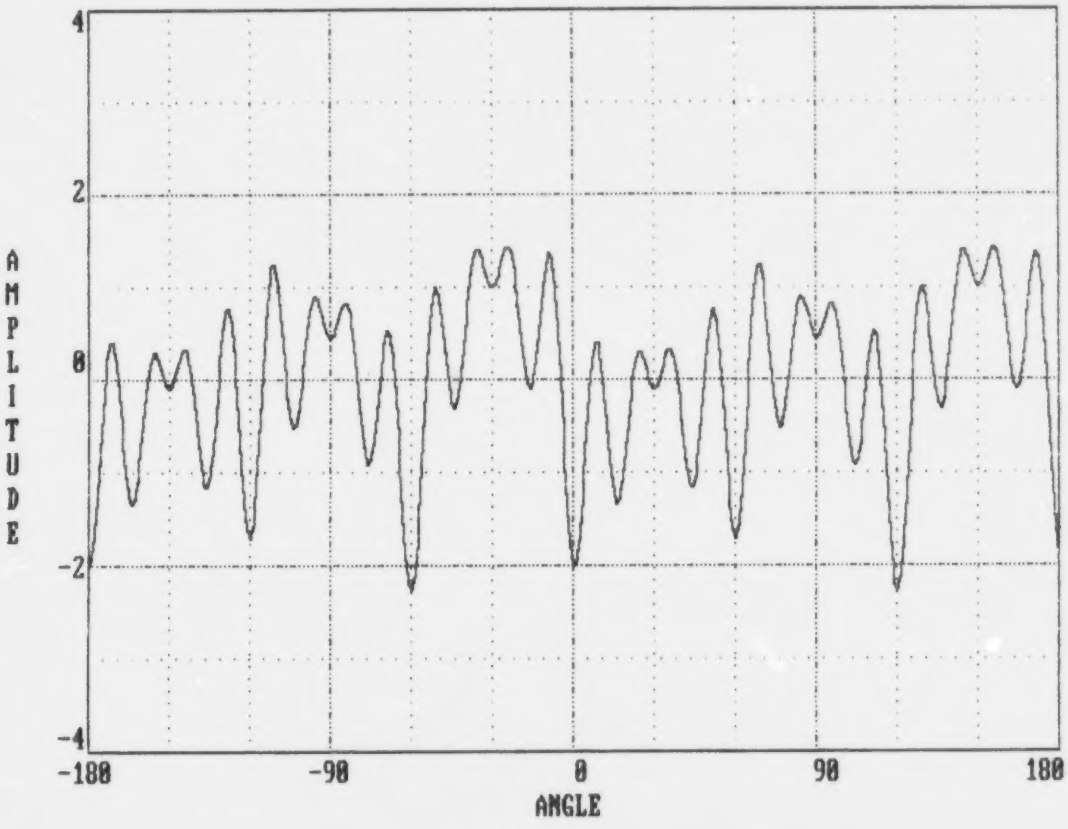


Figure B7. Simulated light intensity at 100 Amps with the designed harmonic filter and a phase-lock-loop SCR firing circuit.

APPENDIX B

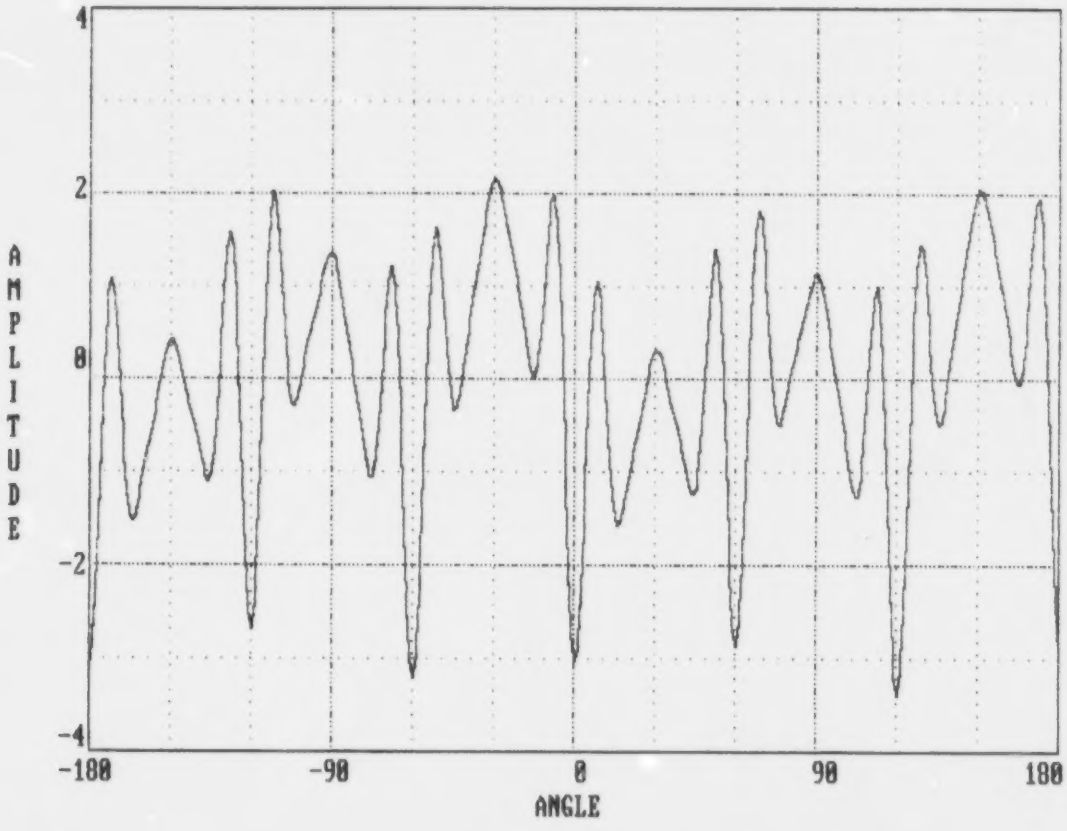


Figure B8. Simulated light intensity at 250 Amps with the designed harmonic filter and a phase-lock-loop SCR firing circuit.

APPENDIX B

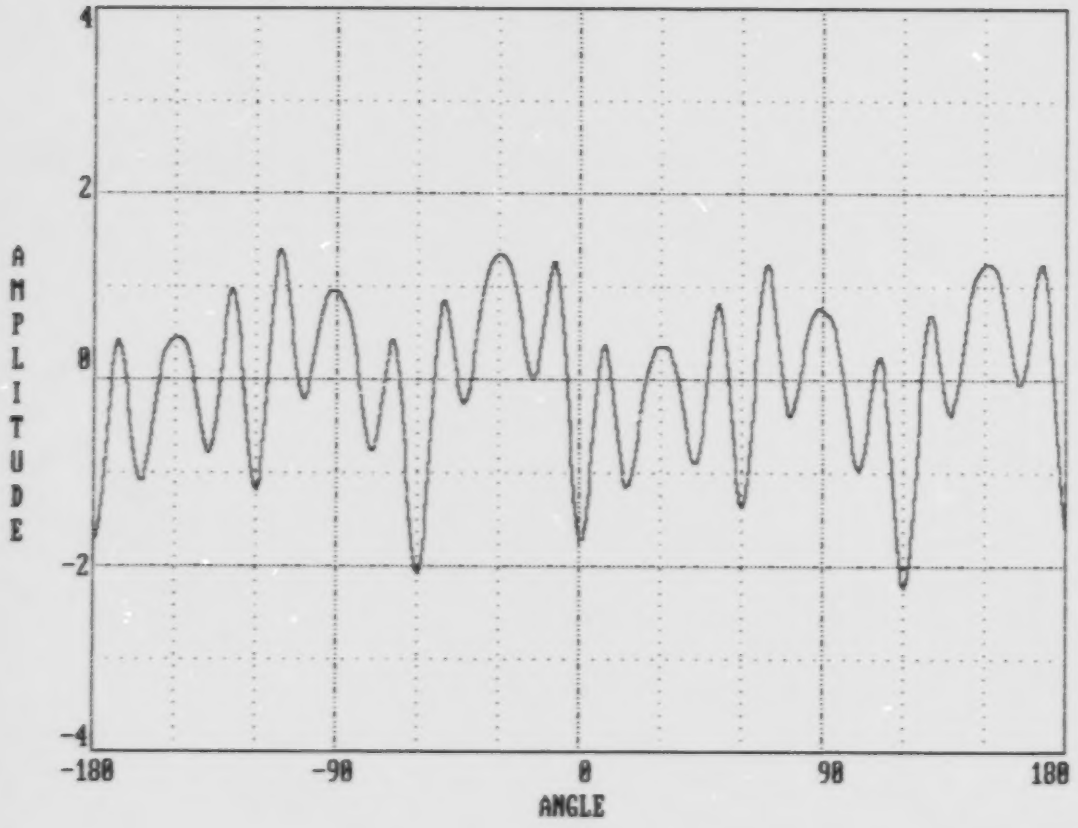


Figure B9. Simulated light intensity at 350 Amps with the designed harmonic filter and a phase-lock-loop SCR firing circuit.

APPENDIX C

DATA OF THE FLUCTUATIONS IN THE ARC'S LIGHT INTENSITY

APPENDIX C

The waveform in the upper oscillograph is composed of an average of 128 waveforms, each triggered off the ac line at 50.3 V (+ve slope). In this measurement mode, the signal to noise suppression ratio is 20.5 dB. Each dot represents a computed point with only 500 points shown in the plot out of a total of 1024 points. The average was calculated from 833 points since this represents the largest multiple of 120 Hz, as 120 Hz is the lowest harmonic frequency in the waveform. The variations in the average intensity were primarily caused by some misalignment of the Silonex cell at an angle of 90 degrees to the incident light.

The waveform in the lower oscillograph is composed of an upper curve (500 points) and lower curve (500 points) that represents the maximum excursions of 256 waveforms, each triggered off the ac line at 50.3 V (+ve slope). An envelope of 256 waveforms at 1 ms/div time period (20.24 ms) is equivalent to a total of 5.1844 seconds sampling time, that took approximately 10 seconds in duration to complete. The deviation between the two curves was defined as the difference between the maximum (minimum) value of the upper curve and the maximum (minimum) value of the lower curve at each maxima (minima). The number in the brackets after the word Maxima and the word Minima is the number of valid sets of peaks located. The computed average from the upper oscillograph was used in converting the difference into percentage values.

The data from the light intensity measurements in Figures C1 to C108 are summarized in Tables C1 to C6.

APPENDIX C

Similar measurements were made of the arc's voltage and are given in Figures C109 to C120. The difference between the upper and lower curves for the arc's voltage is due primarily to measurement noise and is not random fluctuations as observed in the light intensity. As this oscilloscope captures all glitches greater than a few nano-seconds in envelope mode, the spikes observed in the arc's voltage are most likely due to ground noise.

Similar measurements were made of the arc's current and are given in Figures C121 to C126. The results from the arc's current are obscured by the ground noise from the SCR's producing an extra large difference between the upper and lower curves.

Also a sample of the measurement noise on the light intensity signal is given in Figures C127 and C128.

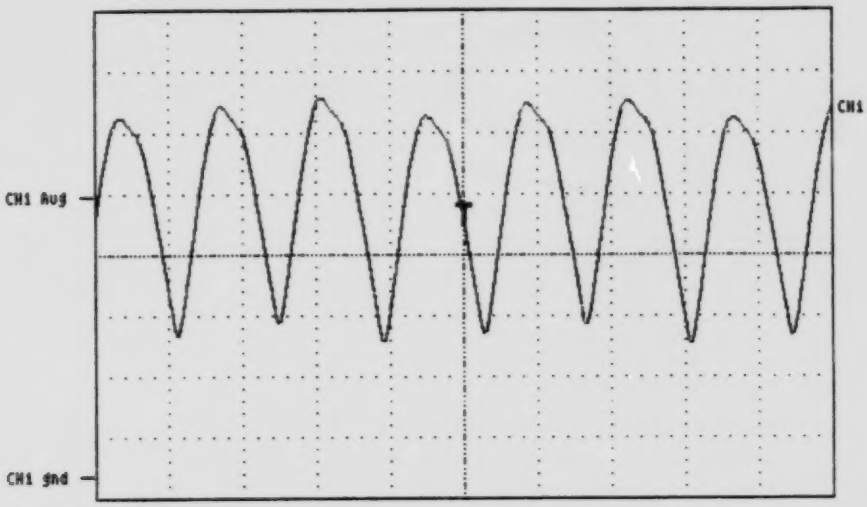
APPENDIX C

Table C1. Summary of data for the arc intensity at 100 Amps.

Figure (#)	Position to center right (in.)	up (in.)	Ripple (%)	Maxima max. (%)	Maxima avg. (%)	Minima max. (%)	Minima avg. (%)
C1	0	6	86.7	18.2	17.5	19.1	16.5
C2	0	18	86.3	17.6	16.2	19.1	17.7
C3	-12	18	86.2	16.9	16.2	19.3	17.5
C4	-26	18	86.6	17.8	16.8	17.8	16.6
C5	-37	18	86.8	25.6	22.8	23.1	20.8
C6	-49	18	86.1	18.7	17.5	17.9	16.6
C7	-57	18	86.7	19.3	18.4	21.0	19.3
C8	-57	12	87.3	21.1	18.6	19.3	17.7
C9	-57	6	88.8	20.7	19.7	20.7	19.7
C10	-57	24	87.5	18.6	17.6	20.3	18.6
C11	13	18	85.1	16.7	15.6	18.3	16.1
C12	25	18	85.1	19.3	17.0	17.7	16.2
C13	33	18	84.5	23.8	21.6	21.3	19.1
C14	46	18	84.1	18.1	16.6	18.1	16.5
C15	46	12	85.7	27.4	21.7	21.4	19.2
C16	46	6	87.7	21.7	19.8	20.7	19.3
C17	46	24	84.9	16.2	15.6	17.8	15.7
C18	46	24	84.9	17.0	16.4	17.0	15.6
Average			86.17	19.71	18.09	19.44	17.71
Std. Dev.			1.21	3.07	2.13	1.62	1.53

Figure C1 Light intensty @ 100 A. (6 in. up; center)

CH1 2 mVΩ (Avg 9.23 mV, Max 12.4 mV, Min 4.42 mV, Rip 86.7%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mVΩ (Maxima(7): δMax 1.68 mV(18.2%), δAvg 1.61 mV(17.5%))
(Minima(7): δMax 1.76 mV(19.1%), δAvg 1.52 mV(16.5%))
A 2 ms 50.30 V LINE Env:256

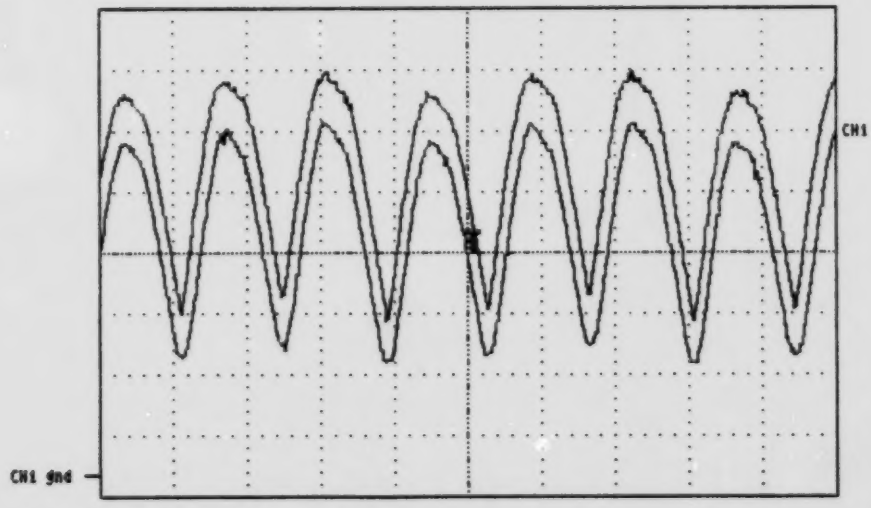
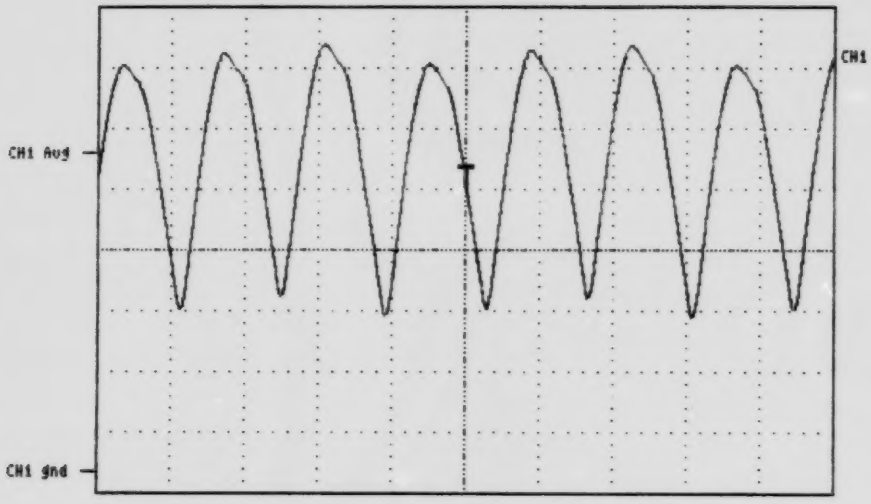


Figure C2 Light intensty @ 100 A. (18 in. up; center)

CH1 2 mVΩ (Avg 10.5 mV, Max 14.1 mV, Min 5.06 mV, Rip 86.3%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mVΩ (Maxima(7): δMax 1.84 mV(17.6%), δAvg 1.70 mV(16.2%))
(Minima(7): δMax 2.00 mV(19.1%), δAvg 1.85 mV(17.7%))
A 2 ms 50.30 V LINE Env:256

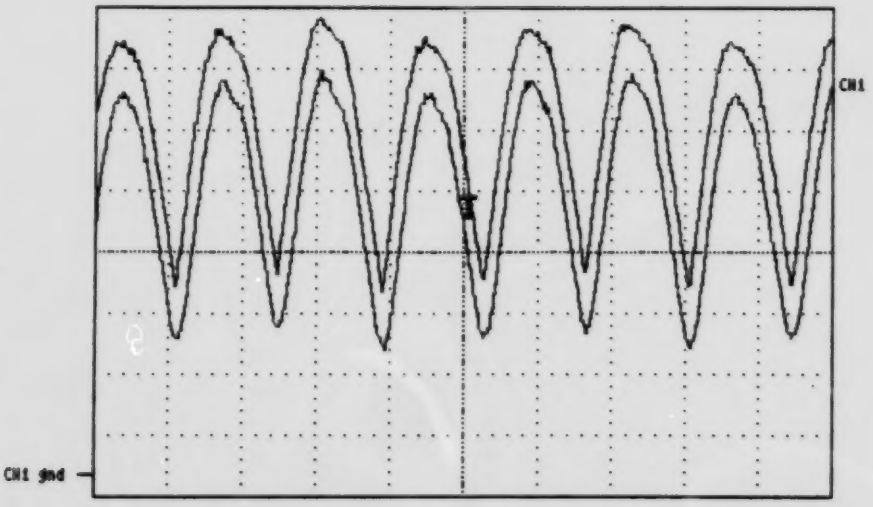
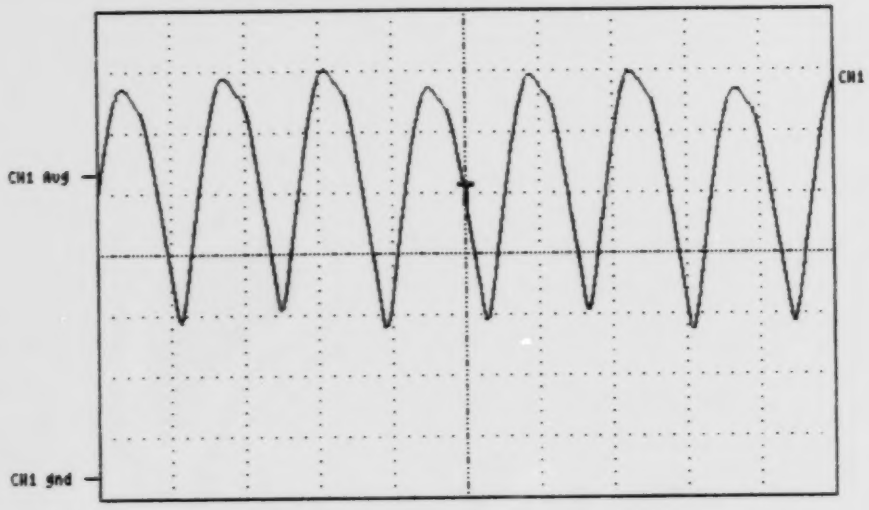


Figure C3 Light intensty @ 100 A. (18 in. up; 12 in. left)

CH1 2 mVΩ (Avg 9.93 mV, Max 13.4 mV, Min 4.82 mV, Rip 86.2%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mVΩ (Maxima(7): δMax 1.68 mV(16.9%), δAvg 1.61 mV(16.2%))
(Minima(7): δMax 1.92 mV(19.3%), δAvg 1.74 mV(17.5%))
A 2 ms 50.30 V LINE Env:256

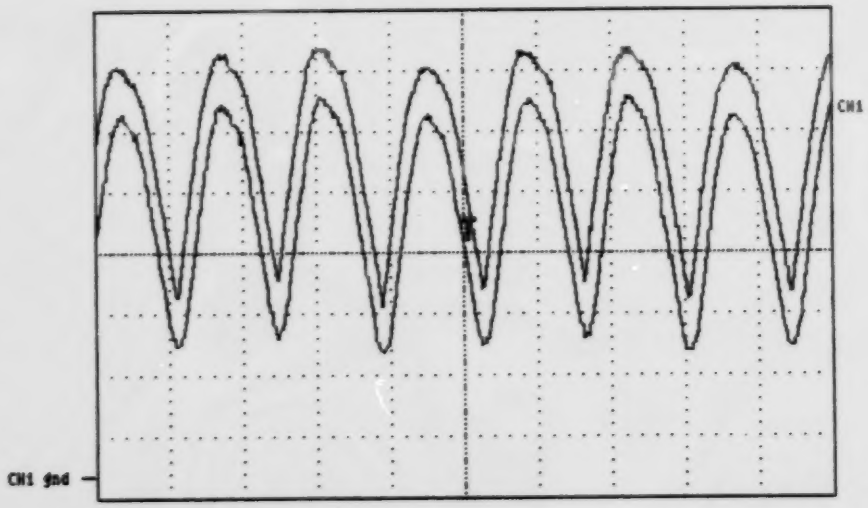
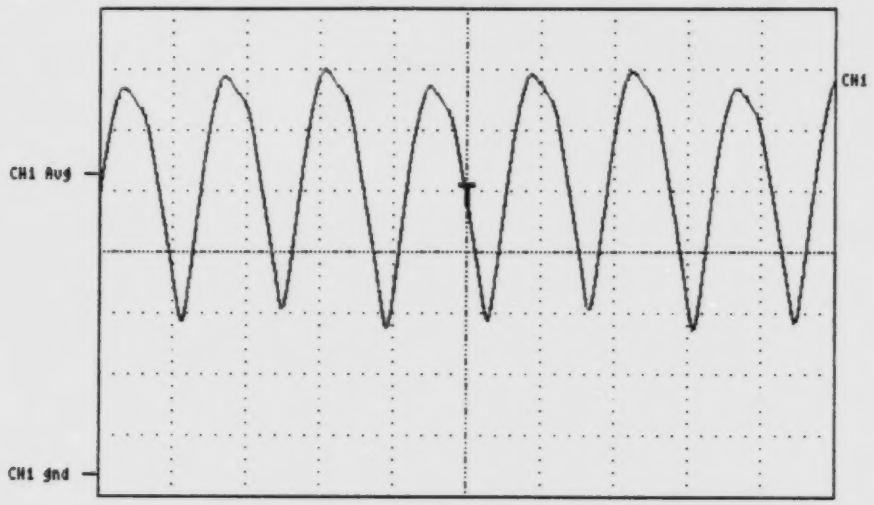


Figure C4 Light intensty @ 100 A. (18 in. up; 26 in. left)

CH1 2 mVΩ (Avg 9.89 mV, Max 13.3 mV, Min 4.74 mV, Rip 86.6%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mVΩ (Maxima(7): δMax 1.76 mV(17.8%), δAvg 1.66 mV(16.8%))
(Minima(7): δMax 1.76 mV(17.8%), δAvg 1.65 mV(16.6%))
A 2 ms 50.30 V LINE Env:256

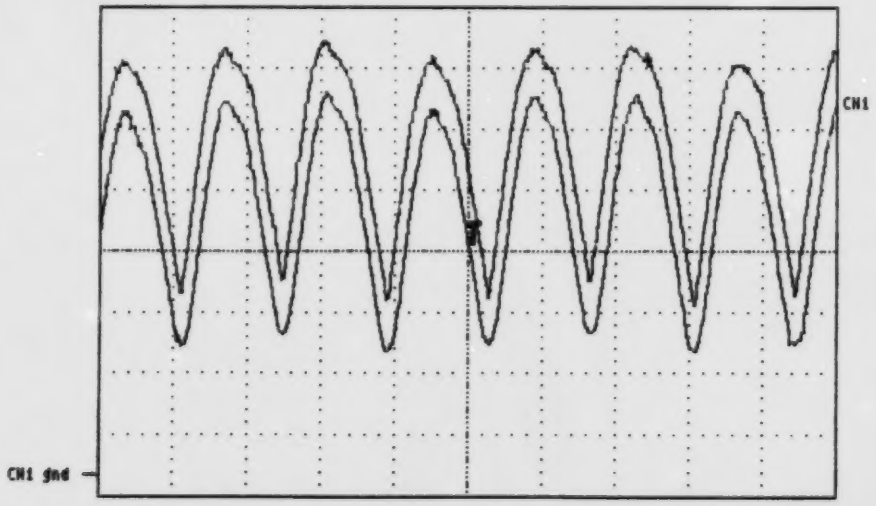
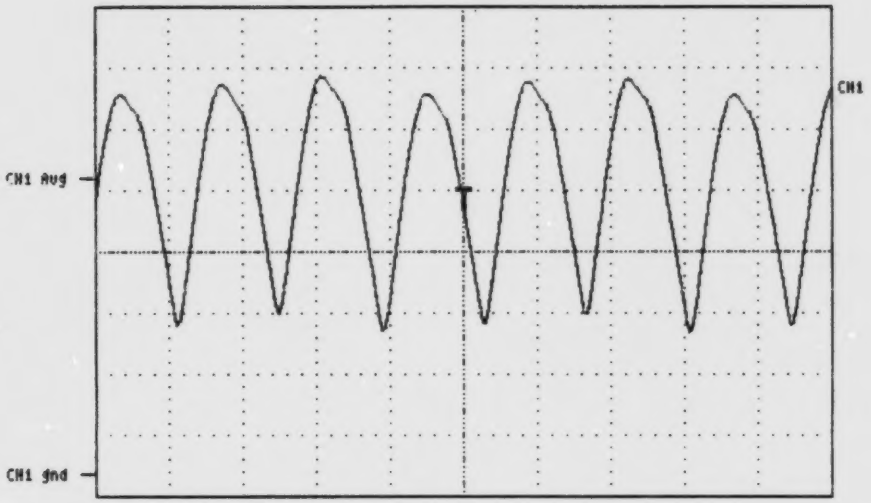


Figure C5 Light intensty @ 100 A. (18 in. up; 37 in. left)

CH1 2 mVΩ (Avg 9.68 mV, Max 13.1 mV, Min 4.66 mV, Rip 86.8%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mVΩ (Maxima(7): δMax 2.48 mV(25.6%), δAvg 2.21 mV(22.8%))
(Minima(7): δMax 2.24 mV(23.1%), δAvg 2.01 mV(20.8%))
A 2 ms 50.30 V LINE Env:256

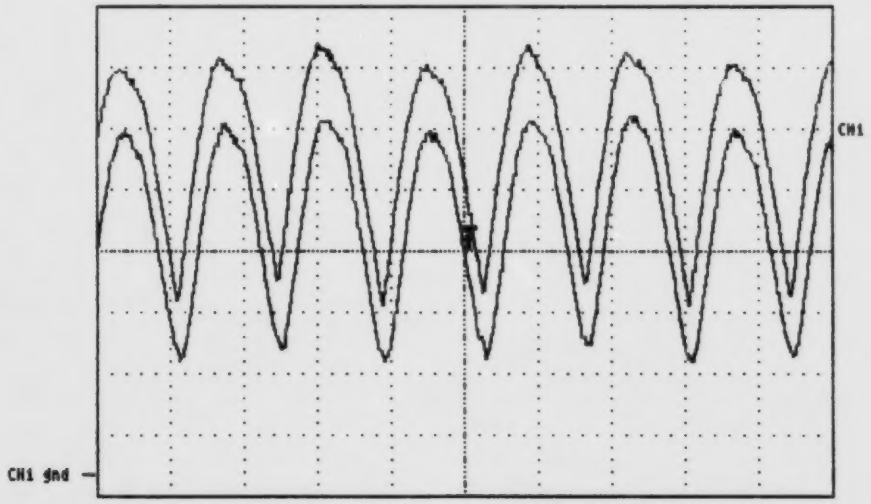
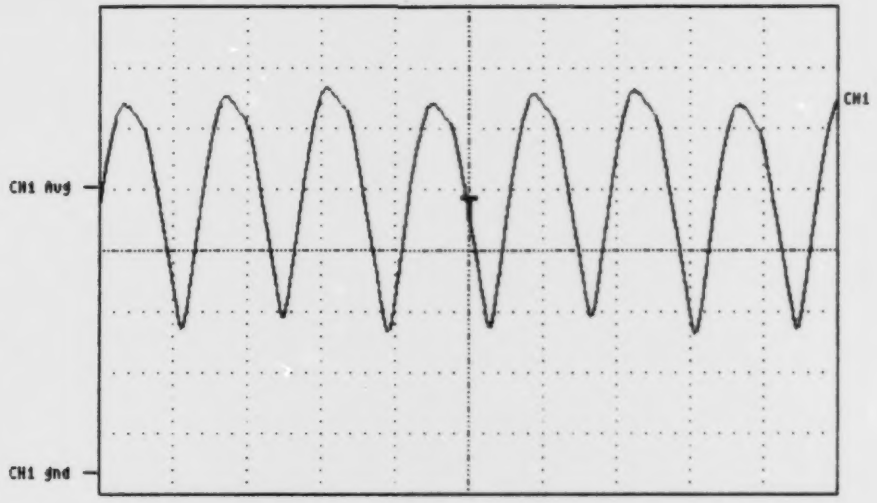


Figure C6 Light intensty @ 100 A. (18 in. up; 49 in. left)

CH1 2 mVΩ (Avg 9.39 mV, Max 12.7 mV, Min 4.58 mV, Rip 86.1%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mVΩ (Maxima(7): δMax 1.76 mV(18.7%), δAvg 1.65 mV(17.5%))
(Minima(7): δMax 1.68 mV(17.9%), δAvg 1.55 mV(16.6%))
A 2 ms 50.30 V LINE Env:256

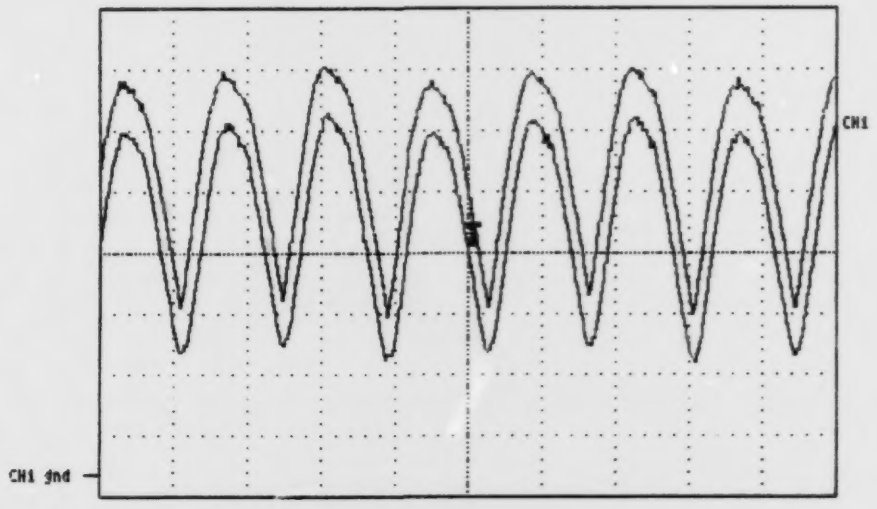
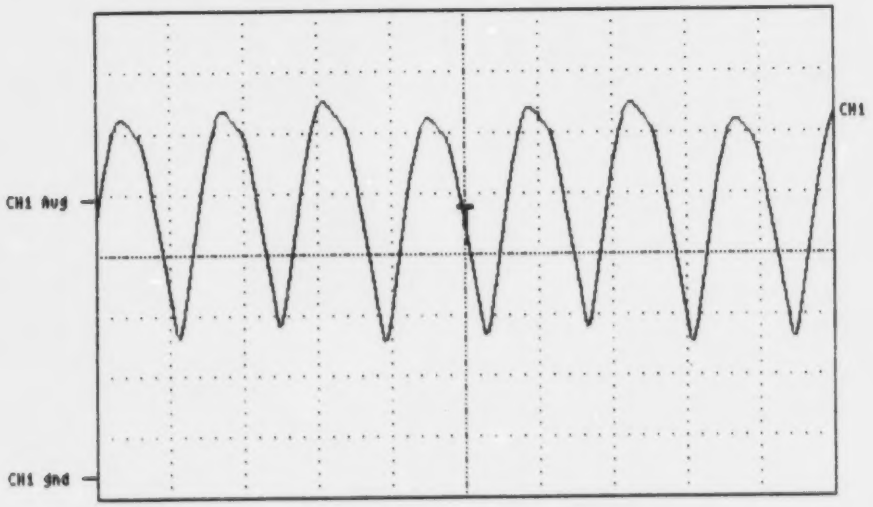


Figure C7 Light intensty @ 100 A. (18 in. up; 57 in. left)

CH1 2 mVΩ (Avg 9.13 mV, Max 12.3 mV, Min 4.42 mV, Rip 86.7%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mVΩ (Maxima(7): δMax 1.76 mV(19.3%), δAvg 1.68 mV(18.4%))
(Minima(7): δMax 1.92 mV(21.8%), δAvg 1.76 mV(19.3%))
A 2 ms 50.30 V LINE Env:256

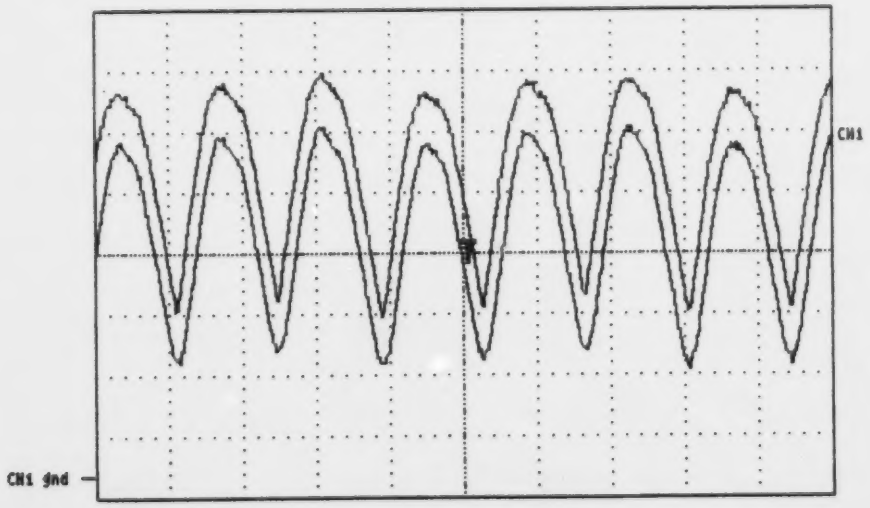
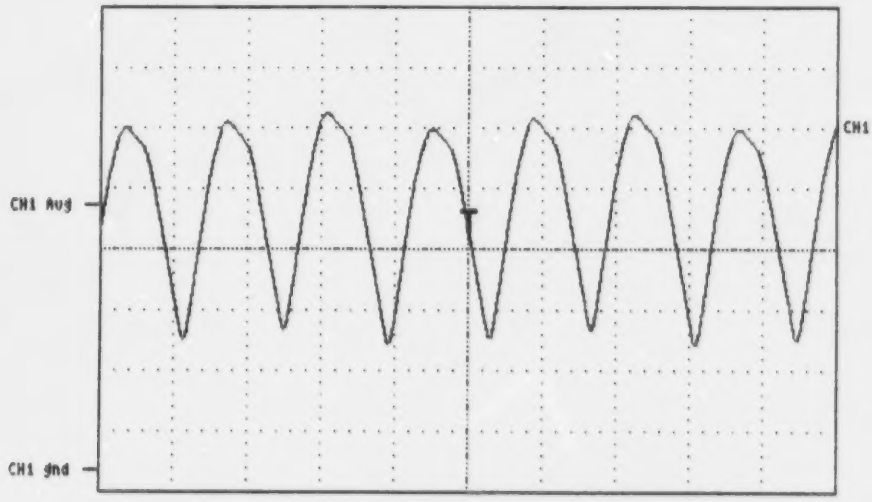


Figure C8 Light intensty @ 100 A. (12 in. up; 57 in. left)

CH1 2 mVΩ (Avg 8.70 mV, Max 11.8 mV, Min 4.18 mV, Rip 87.3%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mVΩ (Maxima(7): δMax 1.84 mV(21.1%), δAvg 1.62 mV(18.6%))
(Minima(7): δMax 1.68 mV(19.3%), δAvg 1.54 mV(17.7%))
A 2 ms 50.30 V LINE Env:256

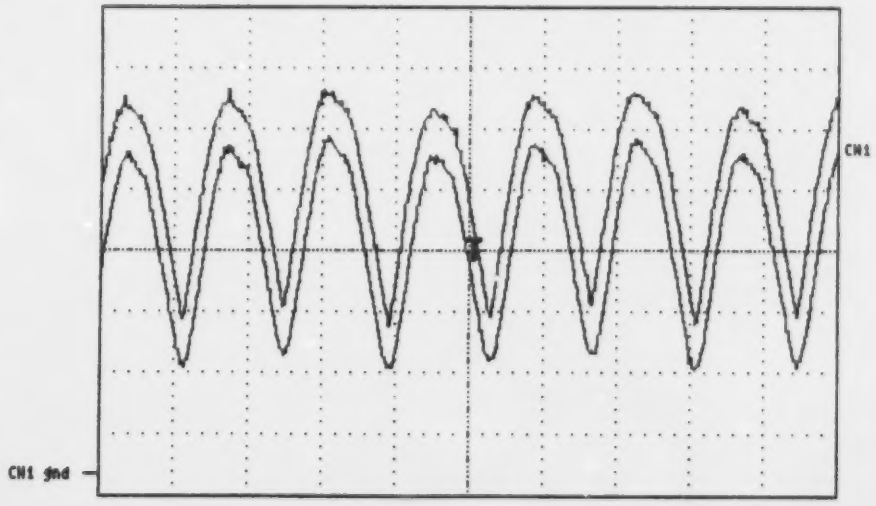
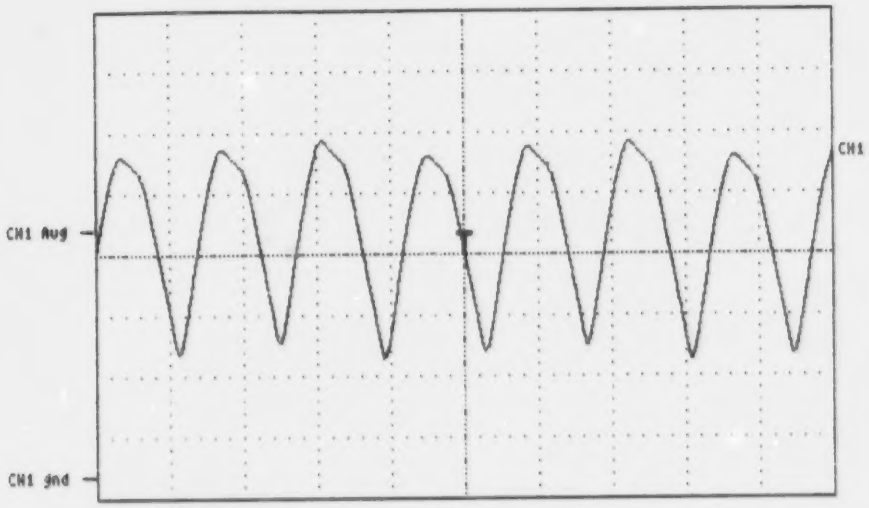


Figure C9 Light intensty @ 100 A. (6 in. up; 57 in. left)

CH1 2 mVΩ (Avg 8.11 mV, Max 11.1 mV, Min 3.86 mV, Rip 88.8%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mVΩ (Maxima(7): δMax 1.68 mV(20.7%), δAvg 1.60 mV(19.7%))
(Minima(7): δMax 1.68 mV(20.7%), δAvg 1.60 mV(19.7%))
A 2 ms 50.30 V LINE Env:256

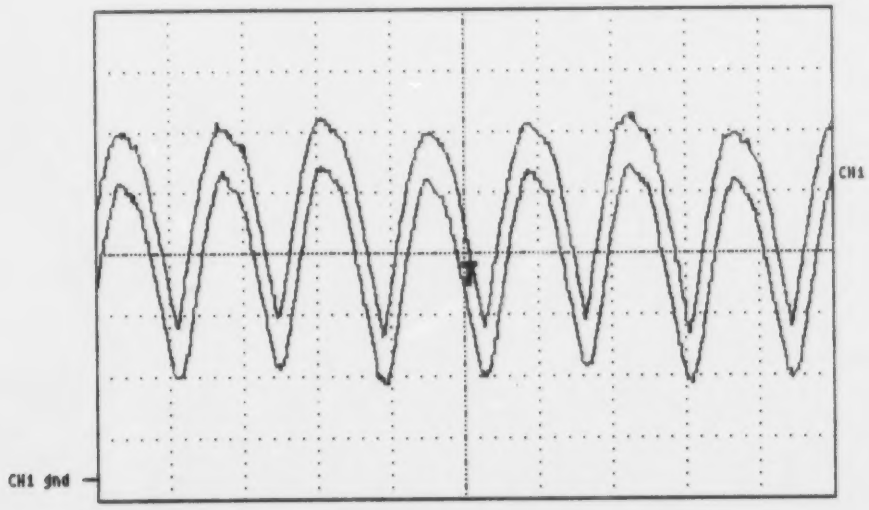
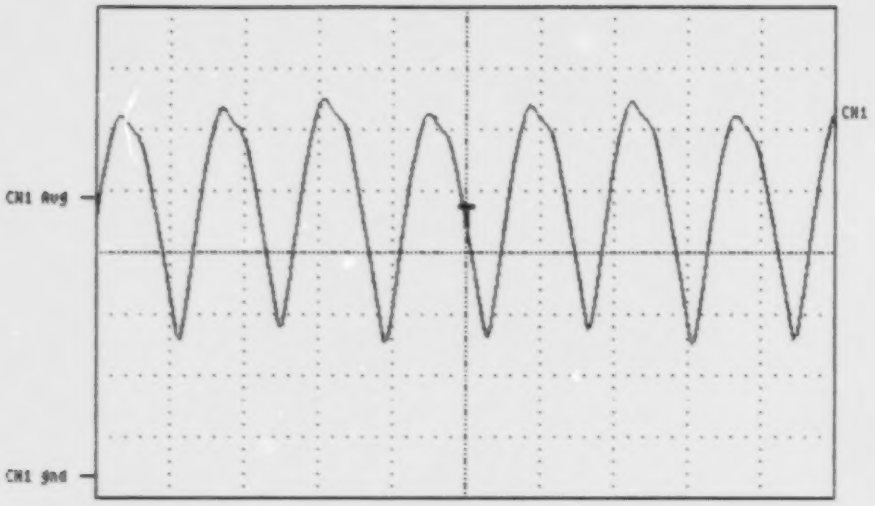


Figure C18 Light intensty @ 100 A. (24 in. up; 57 in. left)

CH1 2 mV Ω (Avg 9.05 mV, Max 12.3 mV, Min 4.34 mV, Rip 87.5%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mV Ω (Maxima(7): δMax 1.68 mV(18.6%), δAvg 1.59 mV(17.6%))
(Minima(7): δMax 1.84 mV(20.3%), δAvg 1.68 mV(18.6%))
A 2 ms 50.30 V LINE Env:256

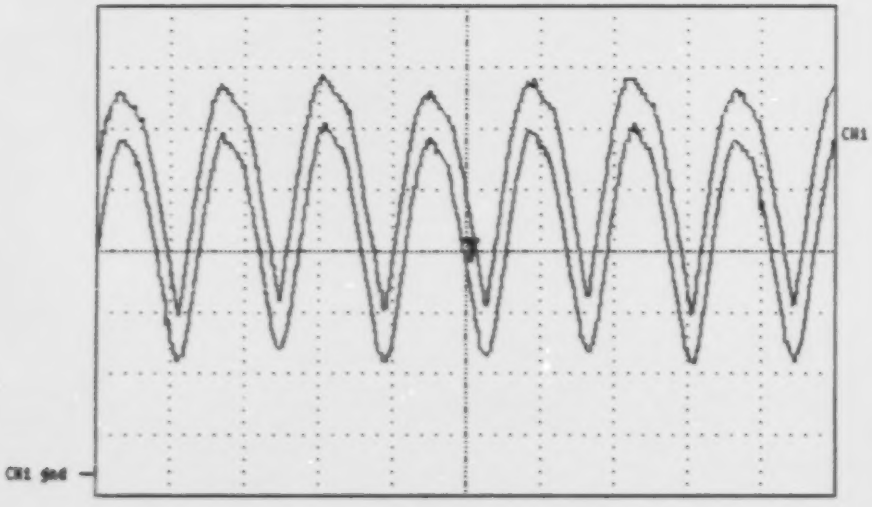
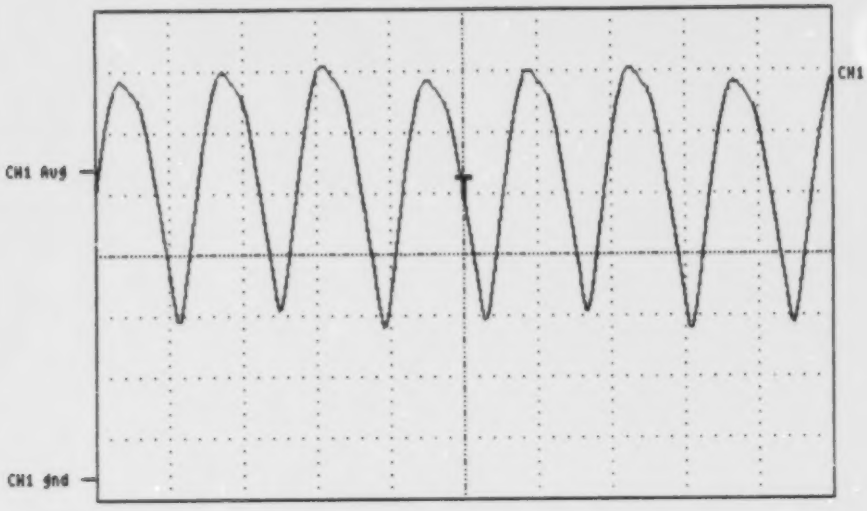


Figure C11 Light intensty @ 100 A. (18 in. up; 13 in. right)

CH1 2 mVΩ (Avg 10.1 mV, Max 13.5 mV, Min 4.90 mV, Rip 85.1%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mVΩ (Maxima(7): δMax 1.68 mV(16.7%), δAvg 1.57 mV(15.6%))
(Minima(7): δMax 1.84 mV(18.3%), δAvg 1.62 mV(16.1%))
A 2 ms 50.30 V LINE Env:256

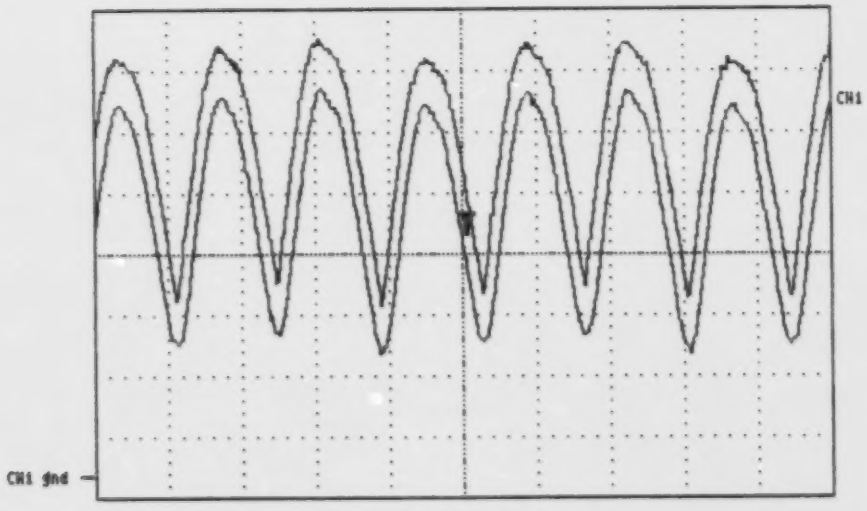
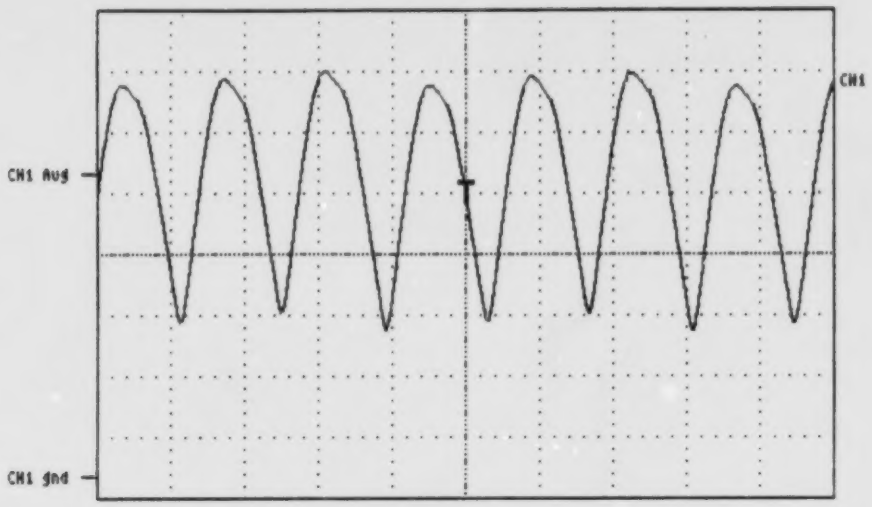


Figure C12 Light intensty @ 100 A. (18 in. up; 25 in. right)

CH1 2 mVΩ (Avg 9.97 mV, Max 13.3 mV, Min 4.82 mV, Rip 85.1%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mVΩ (Maxima(7): δMax 1.92 mV(19.3%), δAvg 1.69 mV(17.0%))
(Minima(7): δMax 1.76 mV(17.7%), δAvg 1.61 mV(16.2%))
A 2 ms 50.30 V LINE Env:256

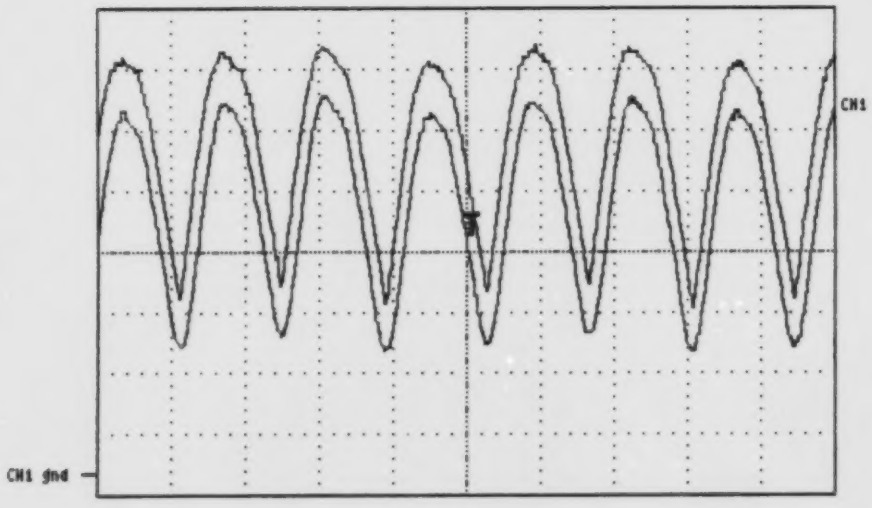
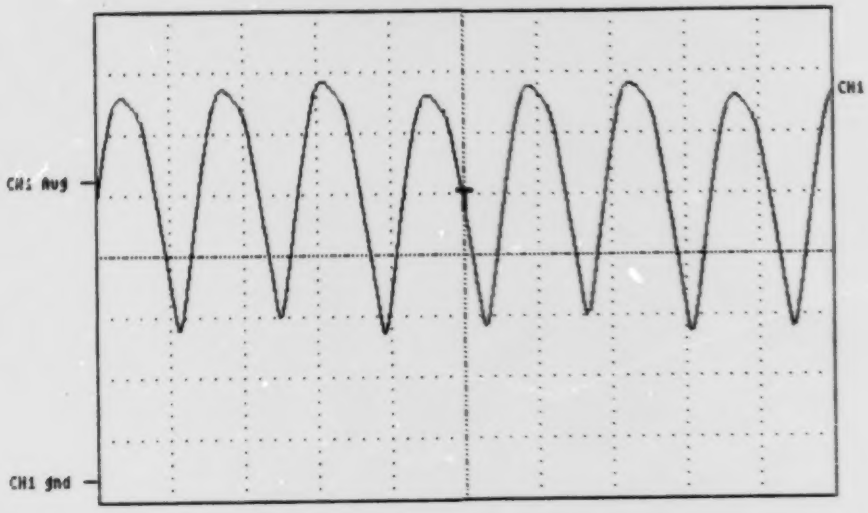


Figure C13 Light intensty @ 100 A. (18 in. up; 33 in. right)

CH1 2 mVΩ (Avg 9.75 mV, Max 13.0 mV, Min 4.74 mV, Rip 84.5%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mVΩ (Maxima(7): δMax 2.32 mV(23.8%), δAvg 2.18 mV(21.6%))
(Minima(7): δMax 2.08 mV(21.3%), δAvg 1.86 mV(19.1%))
A 2 ms 50.30 V LINE Env:256

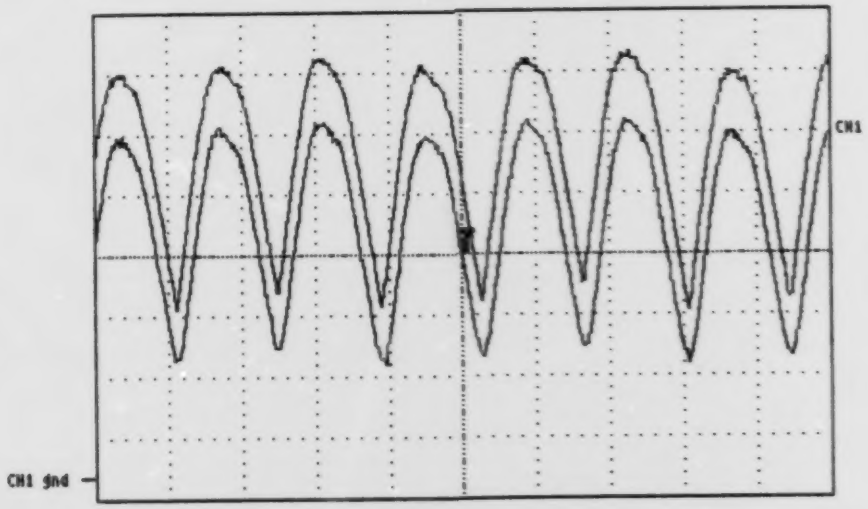
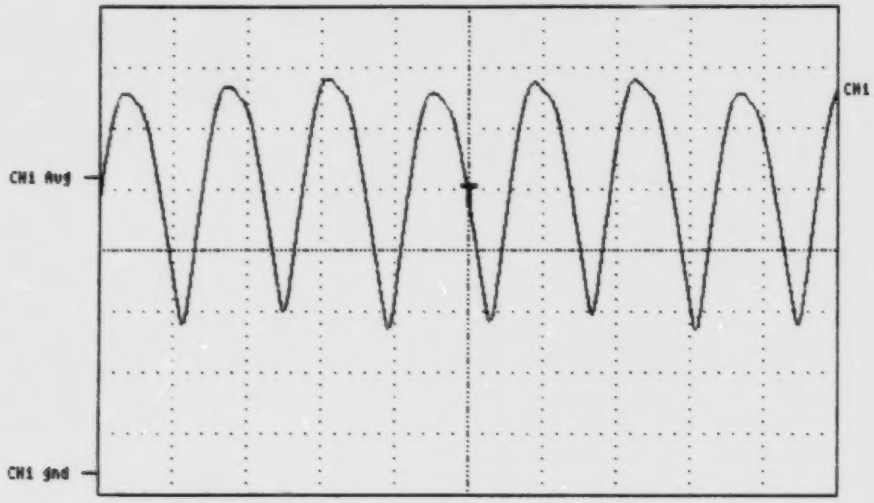


Figure C14 Light intensty @ 100 A. (18 in. up; 46 in. right)

CH1 2 mVΩ (Avg 9.70 mV, Max 12.9 mV, Min 4.74 mV, Rip 84.1%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mVΩ (Maxima(7): δMax 1.76 mV(18.1%), δAvg 1.61 mV(16.6%))
(Minima(7): δMax 1.76 mV(18.1%), δAvg 1.60 mV(16.5%))
A 2 ms 50.30 V LINE Env:256

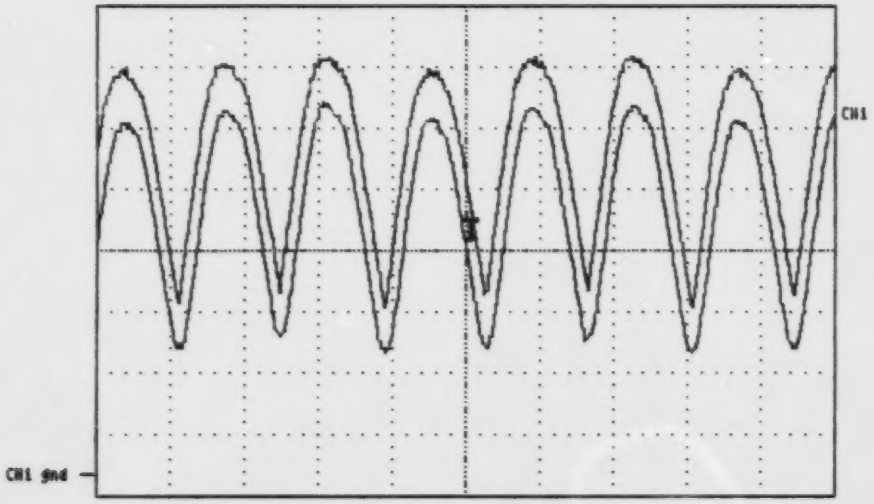
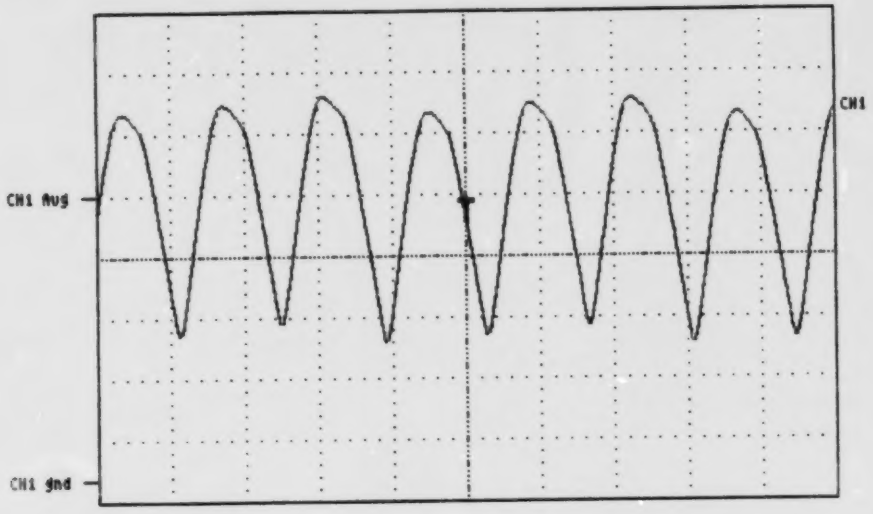


Figure C15 Light intensty @ 100 A. (12 in. up; 46 in. right)

CH1 2 mVΩ (Avg 9.33 mV, Max 12.5 mV, Min 4.50 mV, Rip 85.7%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mVΩ (Maxima(7): δMax 2.56 mV(27.4%), δAvg 2.82 mV(21.7%))
(Minima(7): δMax 2.00 mV(21.4%), δAvg 1.79 mV(19.2%))
A 2 ms 50.30 V LINE Env:256

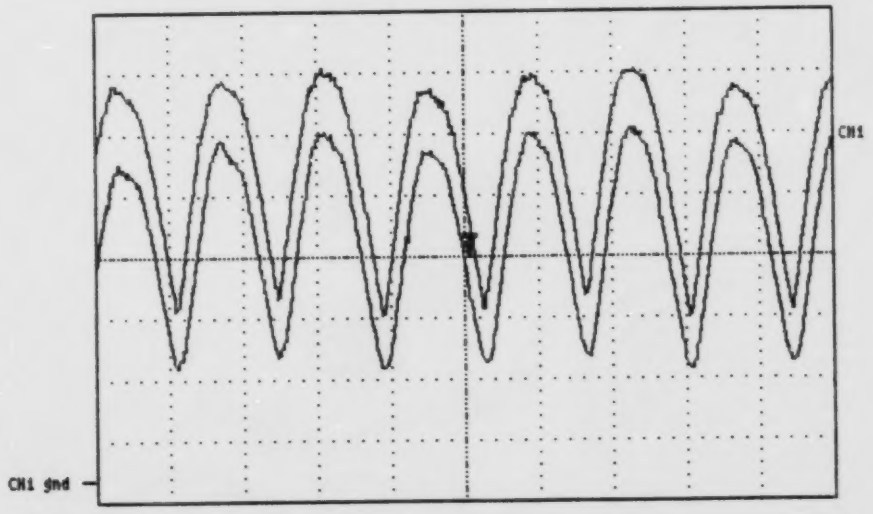
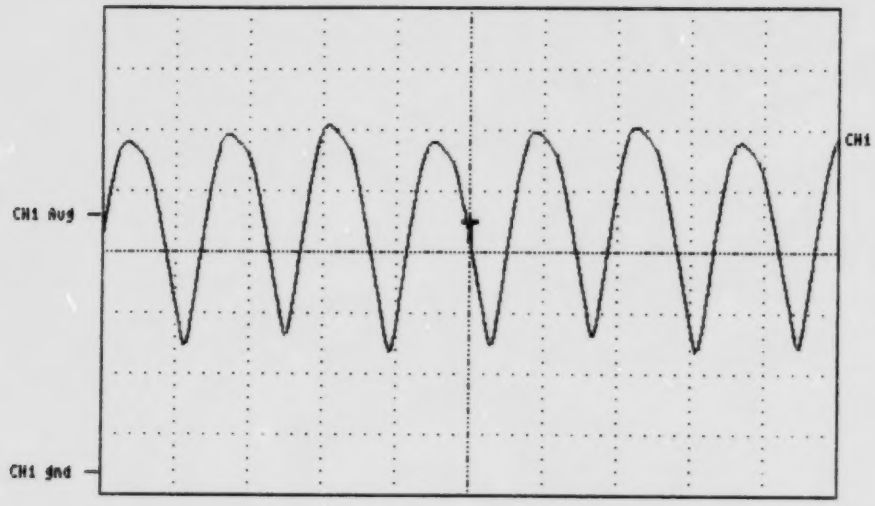


Figure C16 Light intensty @ 100 A. (6 in. up; 46 in. right)

CH1 2 mVΩ (Avg 8.48 mV, Max 11.5 mV, Min 4.82 mV, Rip 87.7%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mVΩ (Maxima(7): δMax 1.84 mV(21.7%), δAvg 1.68 mV(19.8%))
(Minima(7): δMax 1.76 mV(20.7%), δAvg 1.63 mV(19.3%))
A 2 ms 50.30 V LINE Env:256

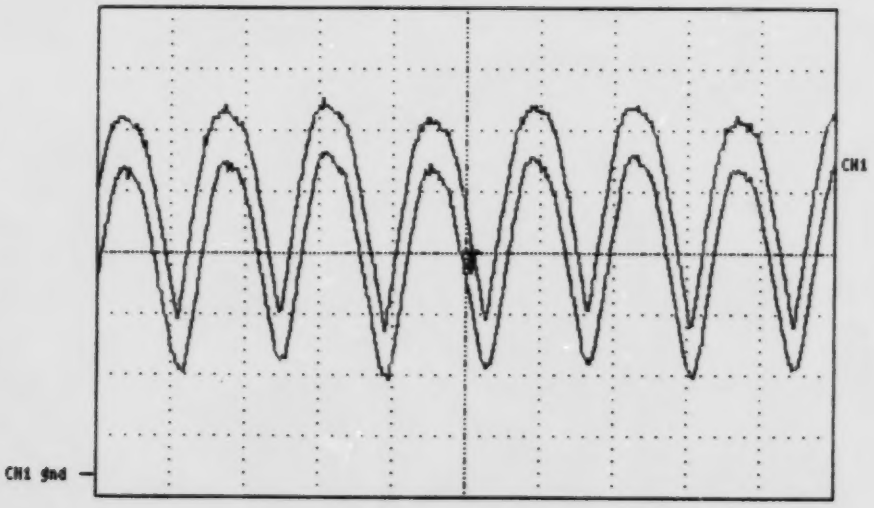
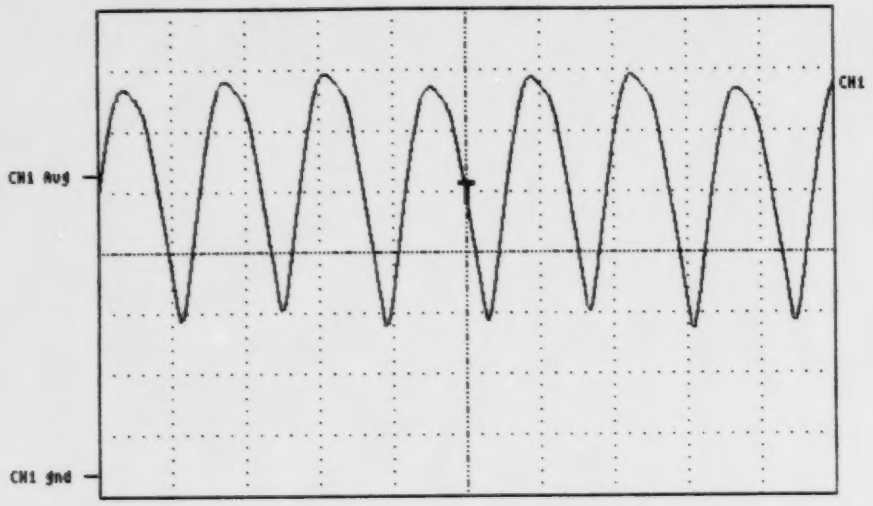


Figure C17 Light intensty @ 100 A. (24 in. up; 46 in. right)

CH1 2 mVΩ (Avg 9.90 mV, Max 13.2 mV, Min 4.82 mV, Rip 84.9%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mVΩ (Maxima(7): δMax 1.60 mV(16.2%), δAvg 1.54 mV(15.6%))
(Minima(7): δMax 1.76 mV(17.8%), δAvg 1.55 mV(15.7%))
A 2 ms 50.30 V LINE Env:256

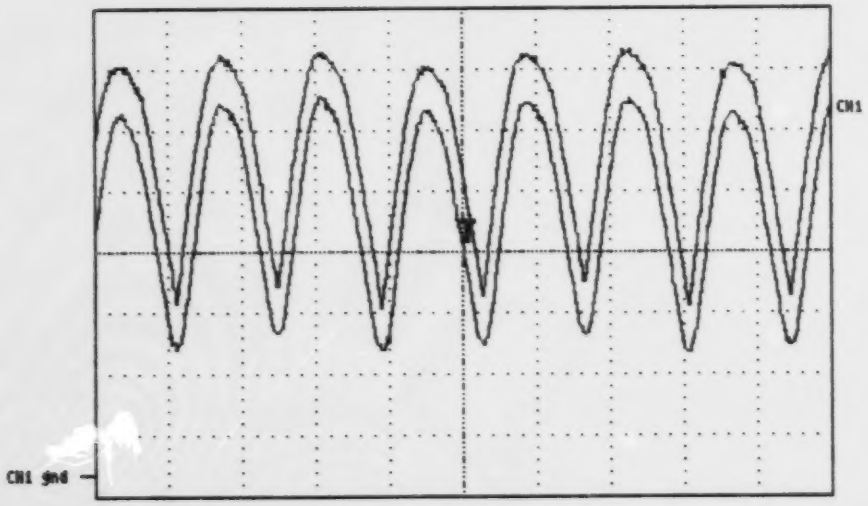
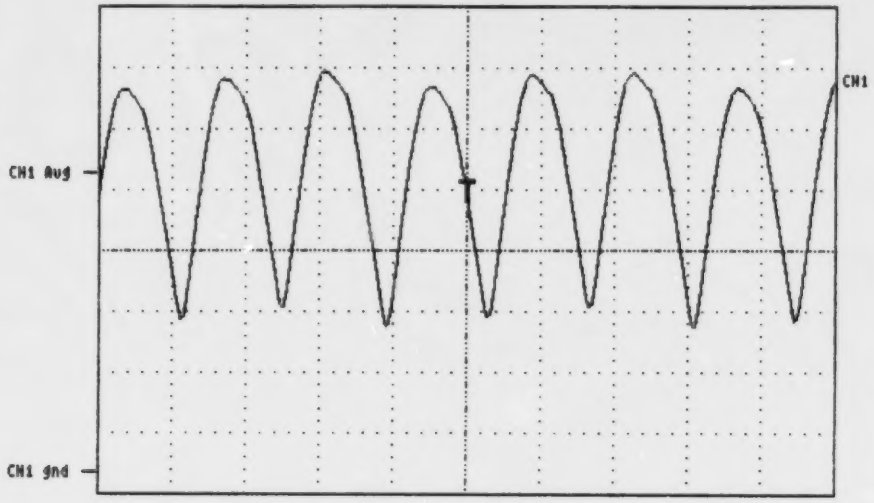
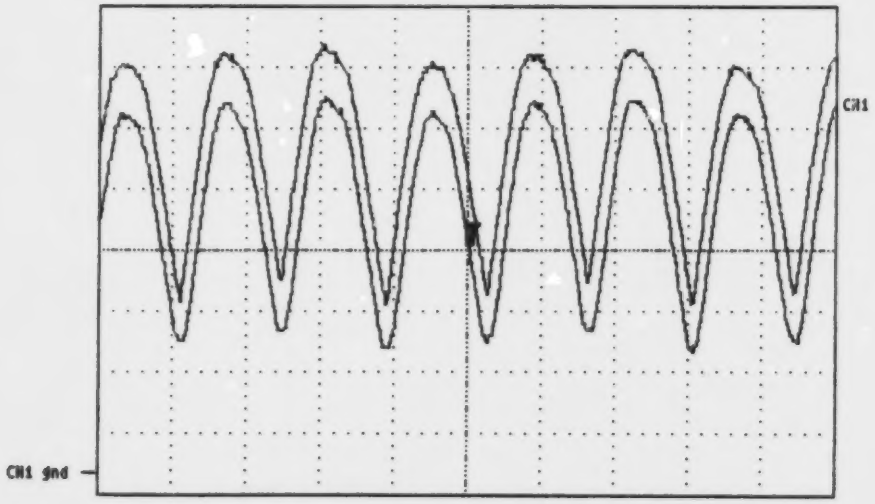


Figure C18 Light intensty @ 100 A. (24 in. up; 46 in. right)

CH1 2 mVΩ (Avg 9.89 mV, Max 13.2 mV, Min 4.82 mV, Rip 84.9%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mVΩ (Maxima(7): δMax 1.60 mV(17.8%), δAvg 1.62 mV(16.4%))
(Minima(7): δMax 1.60 mV(17.8%), δAvg 1.54 mV(15.6%))
A 2 ms 50.30 V LINE Env:256



APPENDIX C

Table C2. Summary of data for the arc intensity at 150 Amps.

Figure (#)	Position to center right (in.)	up (in.)	Ripple (%)	Maxima max. (%)	Maxima avg. (%)	Minima max. (%)	Minima avg. (%)
C19	0	6	60.0	12.2	10.7	12.7	11.8
C20	0	18	58.4	10.9	10.1	13.3	12.4
C21	-12	18	58.8	10.1	9.5	13.0	11.6
C22	-26	18	58.8	13.0	11.6	14.9	13.4
C23	-37	18	59.0	14.3	13.4	15.7	13.7
C24	-49	18	59.0	11.3	10.1	12.3	11.4
C25	-57	18	58.9	12.6	11.6	13.7	12.8
C26	-57	12	59.8	12.4	12.0	16.7	13.9
C27	-57	6	60.5	13.0	12.0	14.7	12.6
C28	-57	24	58.6	11.3	10.7	15.0	13.0
C29	13	18	58.8	10.5	9.9	12.0	10.9
C30	25	18	59.2	9.6	9.3	11.5	11.0
C31	33	18	59.1	15.8	14.3	14.8	13.9
C32	46	18	58.1	11.8	10.5	12.8	11.9
C33	46	12	59.5	11.6	10.7	14.6	13.1
C34	46	6	59.7	12.6	11.9	13.7	12.4
C35	46	24	58.4	10.7	9.3	11.7	10.6
C36	46	24	58.4	10.2	9.6	12.7	11.6
Average			59.06	11.88	10.96	13.66	12.33
Std. Dev.			0.61	1.52	1.36	1.42	1.01

Figure C19 Light intensty @ 150 A. (6 in. up; center)

CH1 2 mVΩ (Avg 15.7 mV, Max 19.3 mV, Min 9.86 mV, Rip 68.8%)
A 2 ms 50.30 V LINE Avg:128

CH1 2 mVΩ (Maxima(7): δMax 1.92 mV(12.2%), δAvg 1.69 mV(10.7%))
(Minima(7): δMax 2.00 mV(12.7%), δAvg 1.86 mV(11.8%))
A 2 ms 50.30 V LINE Env:256

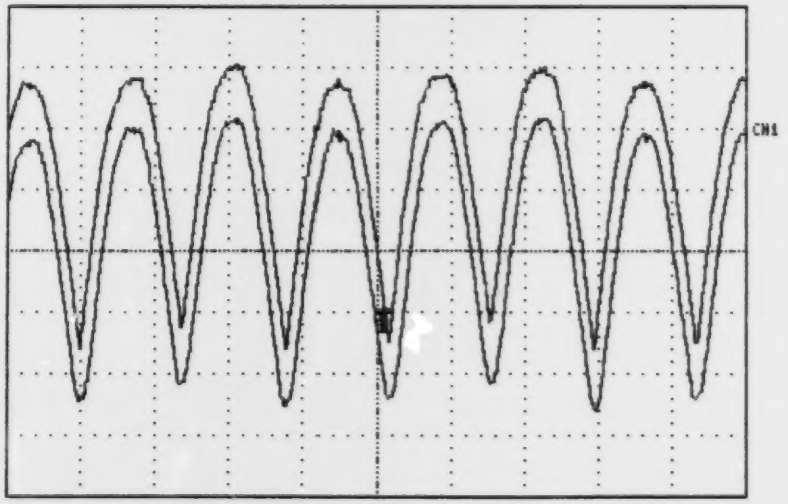
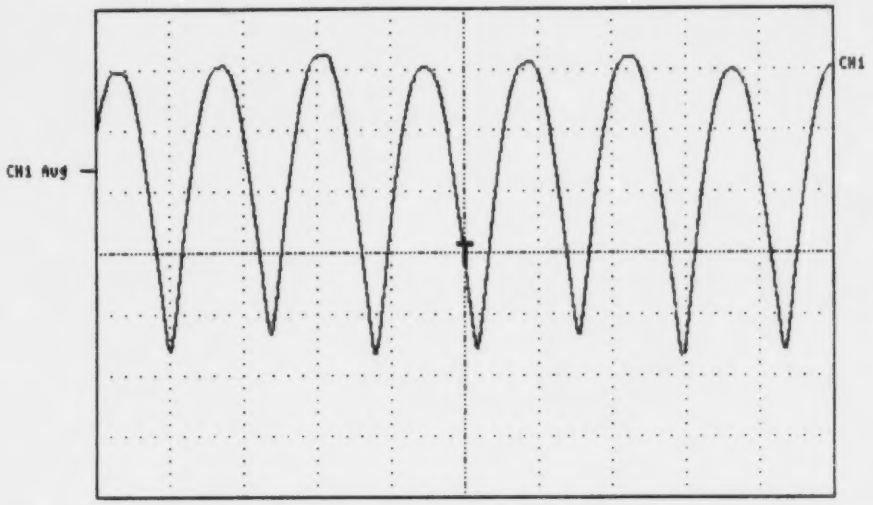


Figure C20 Light intensty @ 150 A. (18 in. up; center)

CH1 2 mVΩ (Avg 16.9 mV, Max 20.6 mV, Min 10.7 mV, Rip 58.4%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mVΩ (Maxima(7): δMax 1.84 mV(10.9%), δAvg 1.70 mV(10.1%))
(Minima(7): δMax 2.24 mV(13.3%), δAvg 2.09 mV(12.4%))
A 2 ms 50.30 V LINE Env:256

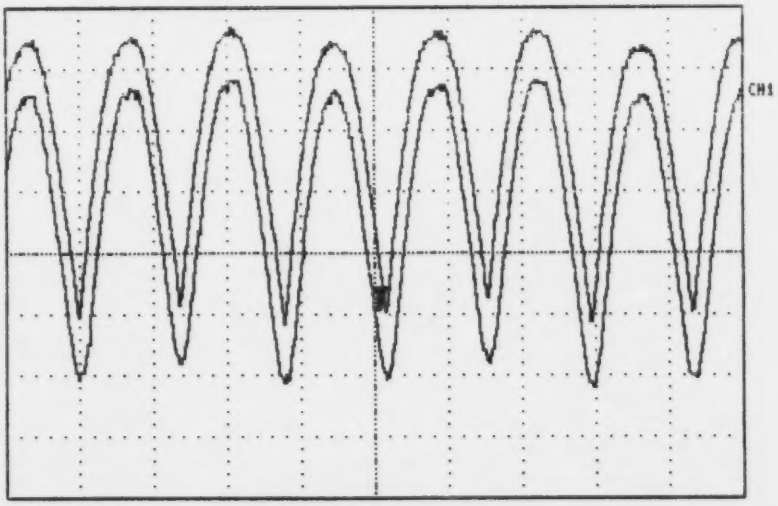
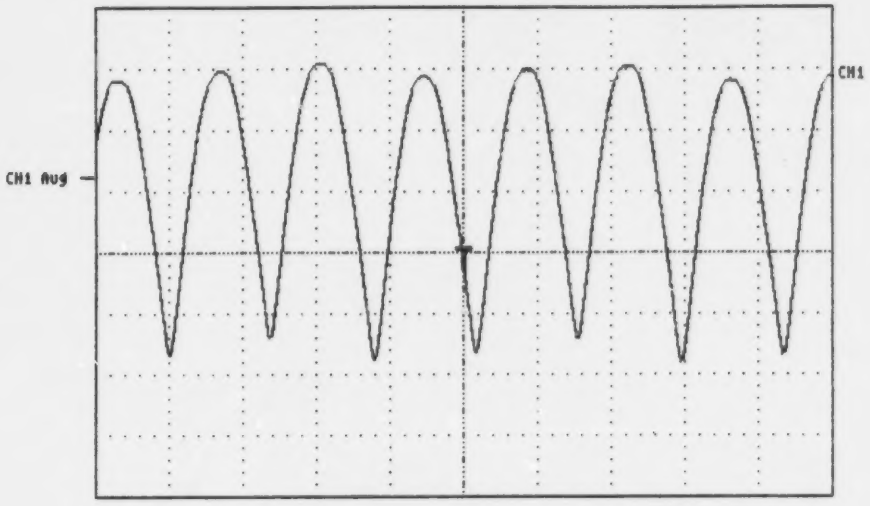


Figure C21 Light intensty @ 150 A. (18 in. up; 12 in. left)

CH1 2 mVΩ (Avg 16.6 mV, Max 20.3 mV, Min 18.5 mV, Rip 58.8%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mVΩ (Maxima(7): δMax 1.68 mV(10.1%), δAvg 1.58 mV(9.5%))
(Minima(7): δMax 2.16 mV(13.0%), δAvg 1.92 mV(11.6%))
A 2 ms 50.30 V LINE Env:256

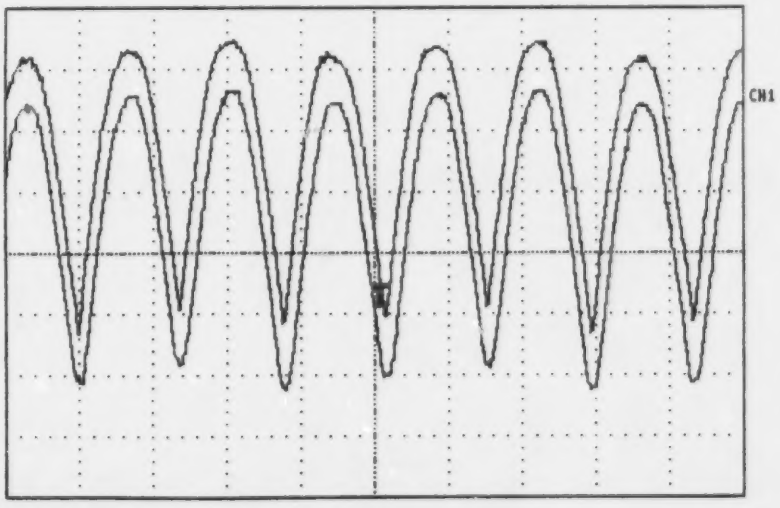
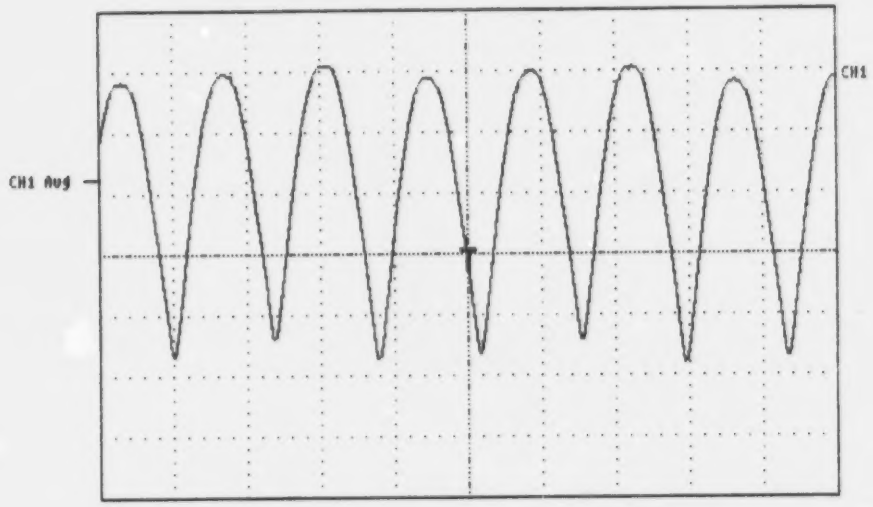


Figure C22 Light intensty @ 150 A. (18 in. up; 26 in. left)

CH1 2 mVΩ (Avg 16.6 mV, Max 20.3 mV, Min 10.5 mV, Rip 58.8%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mVΩ (Maxima(7): δMax 2.16 mV(13.8%), δAvg 1.93 mV(11.6%))
(Minima(7): δMax 2.48 mV(14.9%), δAvg 2.22 mV(13.4%))
A 2 ms 50.30 V LINE Env:256

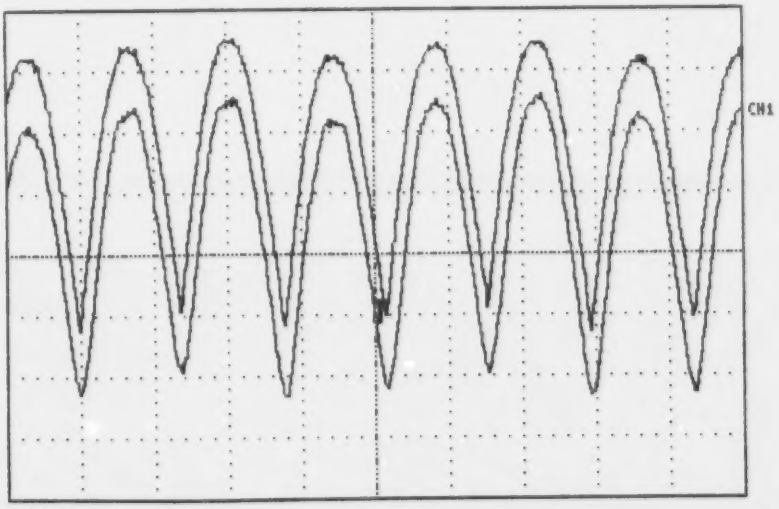
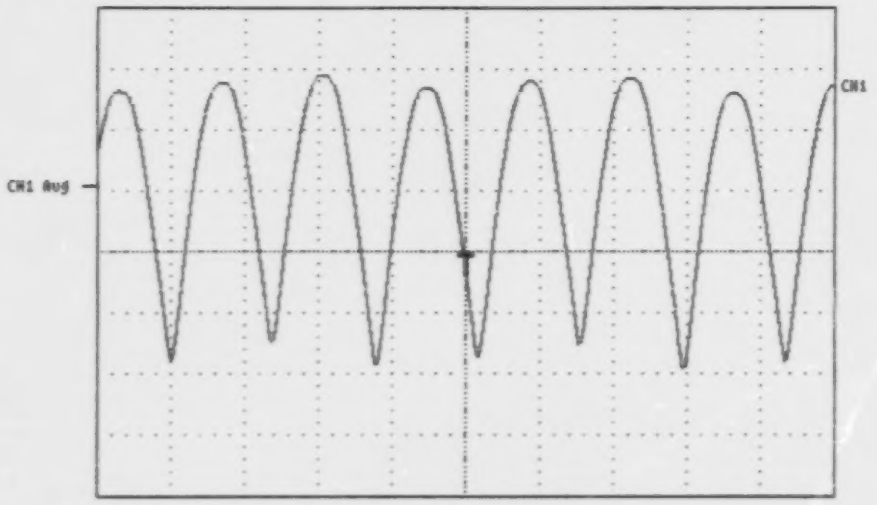


Figure C23 Light intensty @ 150 A. (18 in. up; 37 in. left)

CH1 2 mV Ω (Avg 16.3 mV, Max 19.9 mV, Min 10.3 mV, Rip 59.0%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mV Ω (Maxima(7): δMax 2.32 mV(14.3%), δAvg 2.18 mV(13.4%))
(Minima(7): δMax 2.56 mV(15.7%), δAvg 2.23 mV(13.7%))
A 2 ms 50.30 V LINE Env:256

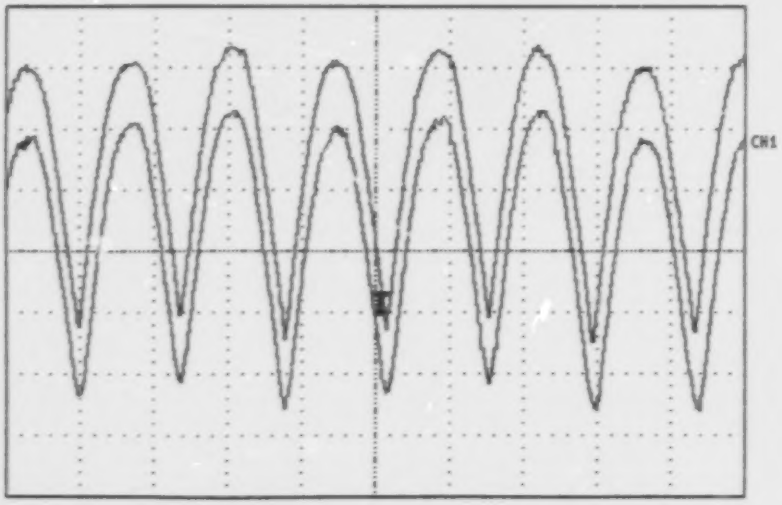
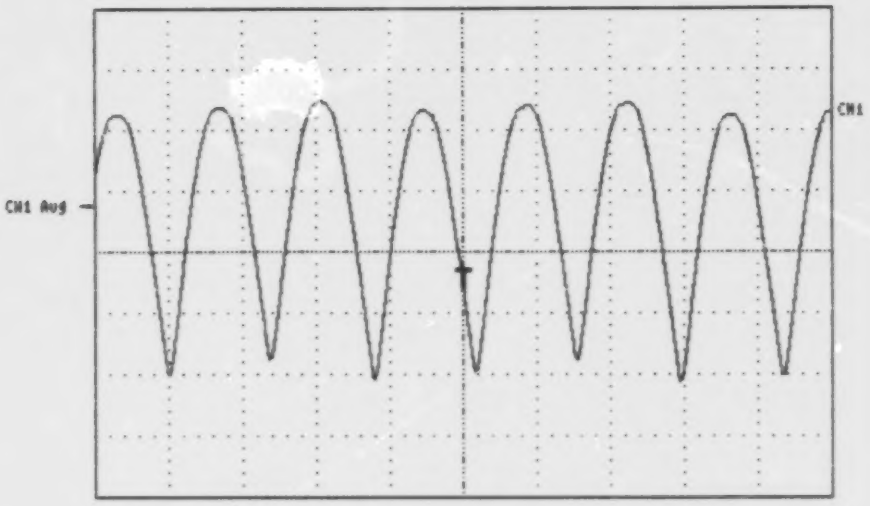


Figure C24 Light intensty @ 150 A. (18 in. up; 49 in. left)

CH1 2 mVΩ (Avg 15.6 mV, Max 19.1 mV, Min 9.86 mV, Rip 59.8%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mVΩ (Maxima(7): δMax 1.76 mV(11.3%), δAvg 1.58 mV(10.1%))
(Minima(7): δMax 1.92 mV(12.3%), δAvg 1.78 mV(11.4%))
A 2 ms 50.30 V LINE Env:256

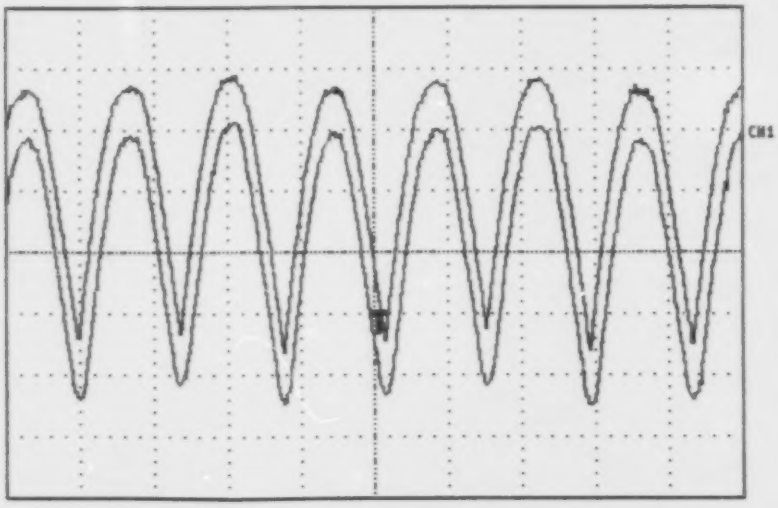
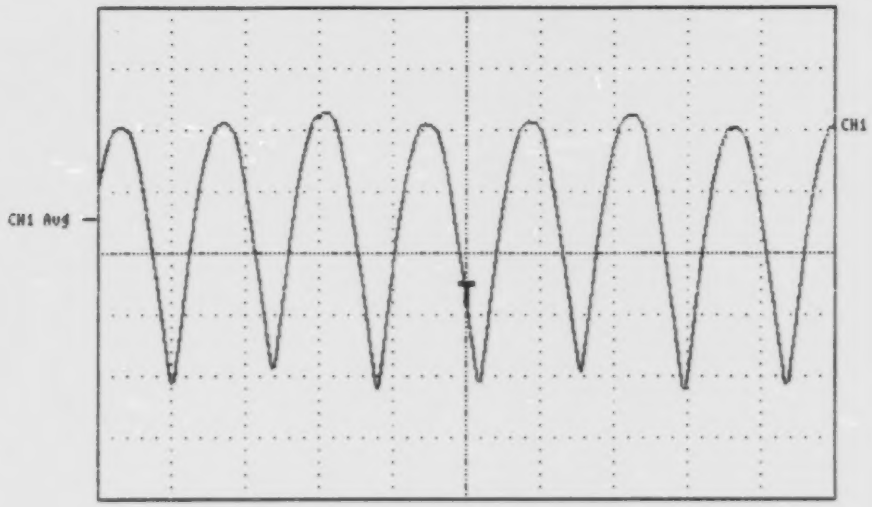


Figure C25 Light intensty @ 150 A. (18 in. up; 57 in. left)

CH1 2 mVΩ (Avg 15.2 mV, Max 18.7 mV, Min 9.70 mV, Rip 58.9%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mVΩ (Maxima(7): δMax 1.92 mV(12.6%), δAvg 1.76 mV(11.6%))
(Minima(7): δMax 2.00 mV(13.7%), δAvg 1.95 mV(12.8%))
A 2 ms 50.30 V LINE Env:256

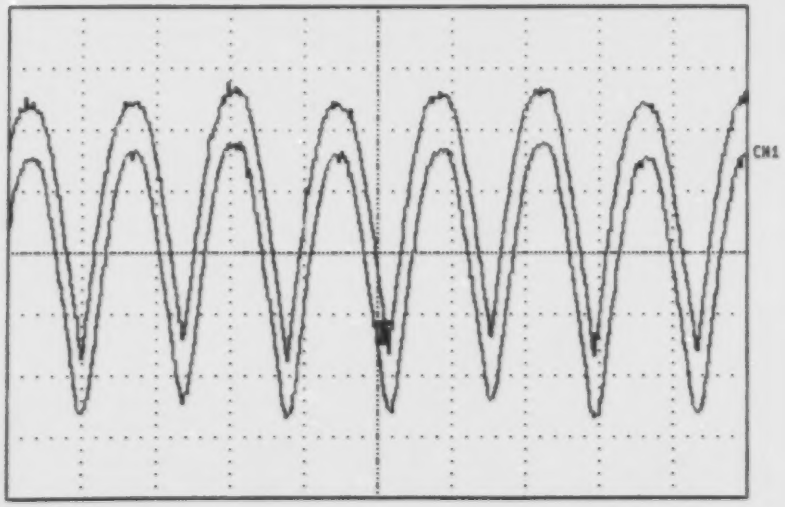
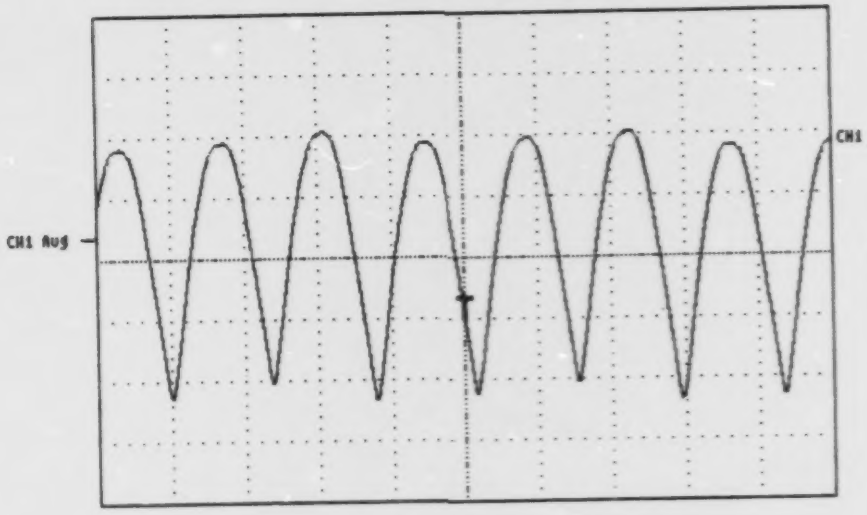


Figure C26 Light intensty @ 158 A. (12 in. up; 57 in. left)

CH1 2 mVΩ (Avg 14.8 mV, Max 18.3 mV, Min 9.38 mV, Rip 59.8%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mVΩ (Maxima(7): δMax 1.84 mV(12.4%), δAvg 1.78 mV(12.8%))
(Minima(7): δMax 2.48 mV(16.7%), δAvg 2.06 mV(13.9%))
A 2 ms 50.30 V LINE Env:256

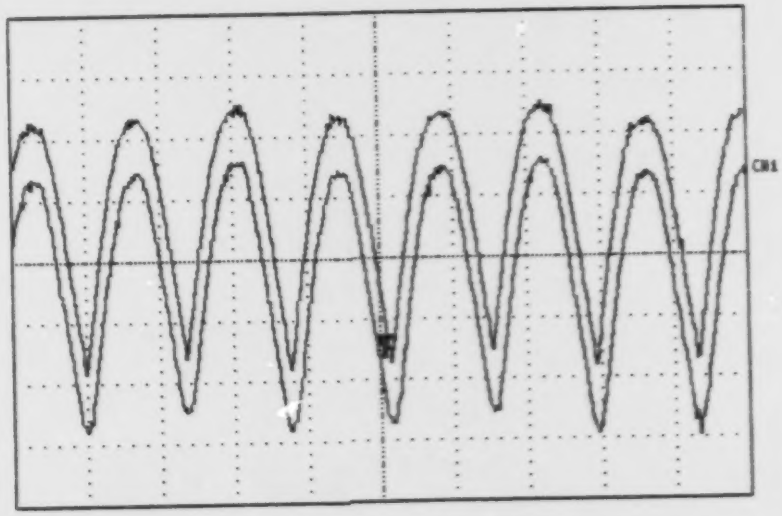
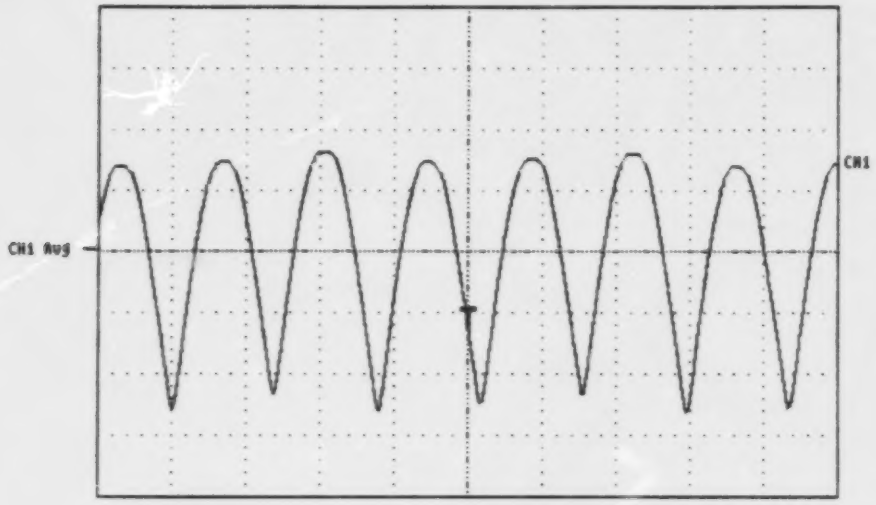


Figure C27 Light intensty @ 150 A. (6 in. up; 57 in. left)

CH1 2 mVΩ (Avg 14.1 mV, Max 17.4 mV, Min 8.82 mV, Rip 68.5%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mVΩ (Maxima(7): δMax 1.84 mV(13.8%), δAvg 1.69 mV(12.8%))
(Minima(7): δMax 2.88 mV(14.7%), δAvg 1.78 mV(12.6%))
A 2 ms 50.30 V LINE Env:256

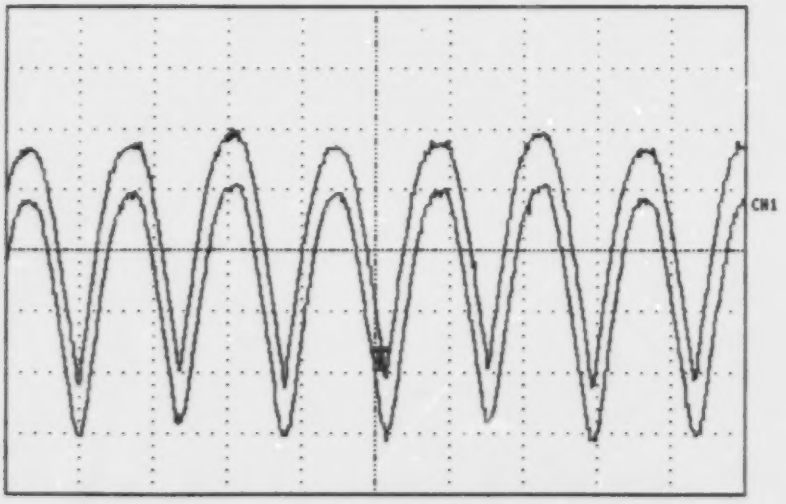
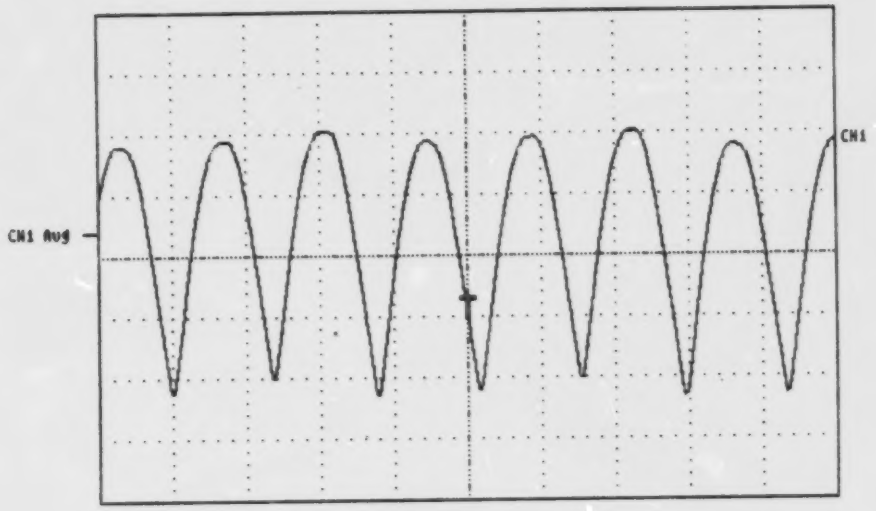


Figure C28 Light intensty @ 150 A. (24 in. up; 57 in. left)

CH1 2 mVΩ (Avg 14.9 mV, Max 18.2 mV, Min 9.46 mV, Rip 58.6%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mVΩ (Maxima(7): δMax 1.68 mV(11.3%), δAvg 1.68 mV(10.7%))
(Minima(7): δMax 2.24 mV(15.0%), δAvg 1.94 mV(13.0%))
A 2 ms 50.30 V LINE Env:256

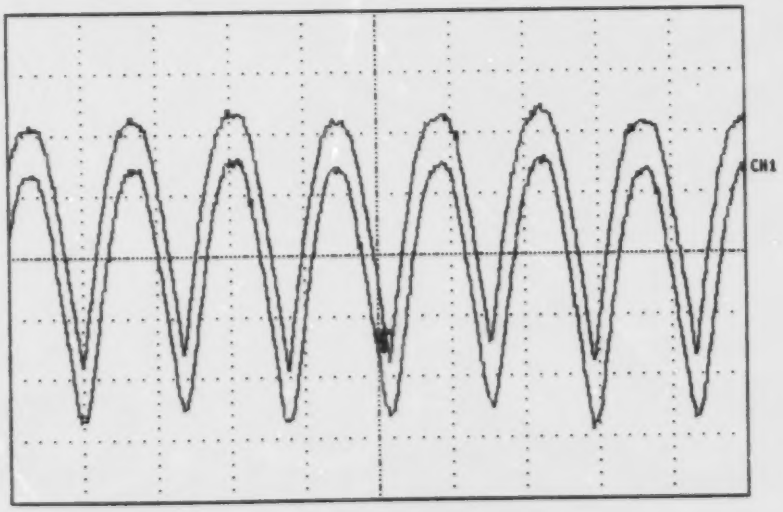
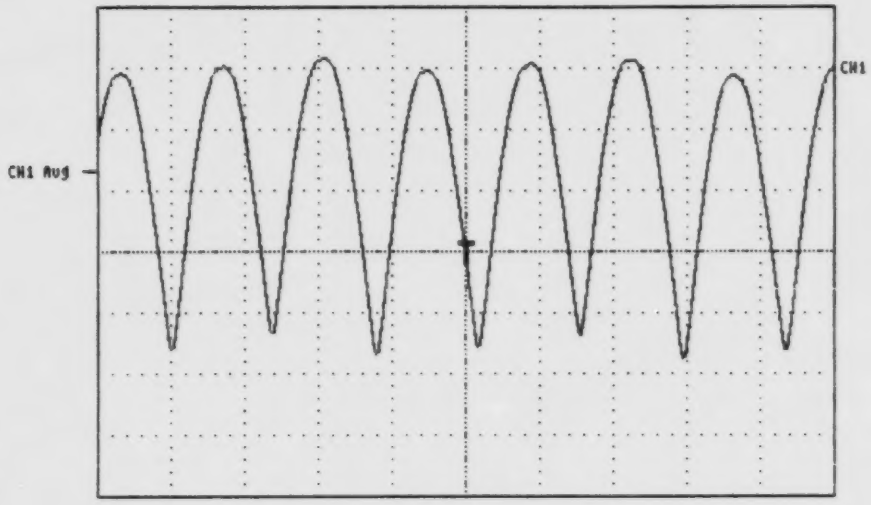


Figure C29 Light intensty @ 150 A. (18 in. up; 13 in. right)

CH1 2 mVΩ (Avg 16.7 mV, Max 20.4 mV, Min 10.6 mV, Rip 58.8%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mVΩ (Maxima(7): δMax 1.76 mV(10.5%), δAvg 1.66 mV(9.9%))
(Minima(7): δMax 2.00 mV(12.0%), δAvg 1.83 mV(10.9%))
A 2 ms 50.30 V LINE Env:256

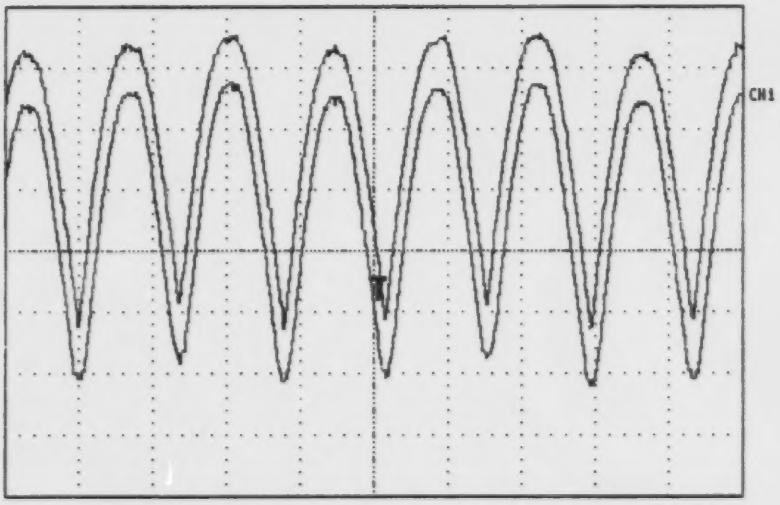
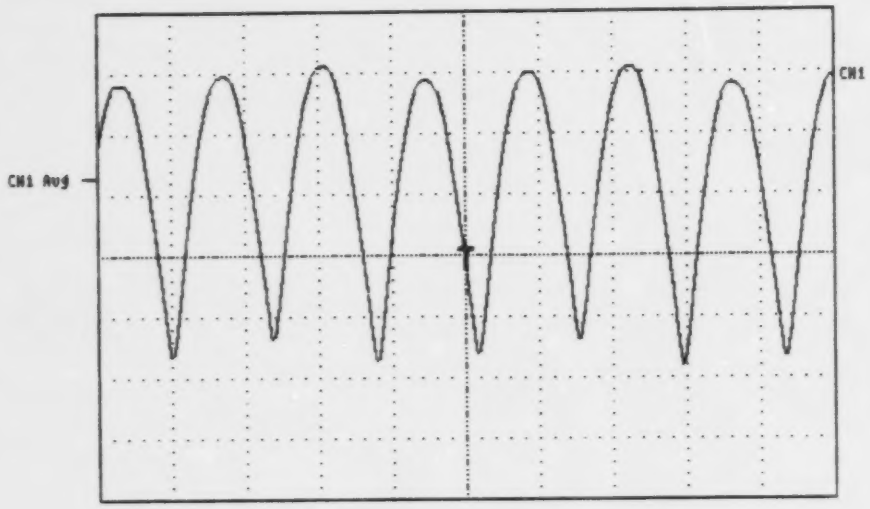


Figure C30 Light intensty @ 150 A. (18 in. up; 25 in. right)

CH1 2 mVΩ (Avg 16.6 mV, Max 20.3 mV, Min 10.5 mV, Rip 59.2%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mVΩ (Maxima(7): δMax 1.60 mV(9.6%), δAvg 1.55 mV(9.3%))
(Minima(7): δMax 1.92 mV(11.5%), δAvg 1.83 mV(11.0%))
A 2 ms 50.30 V LINE Env:256

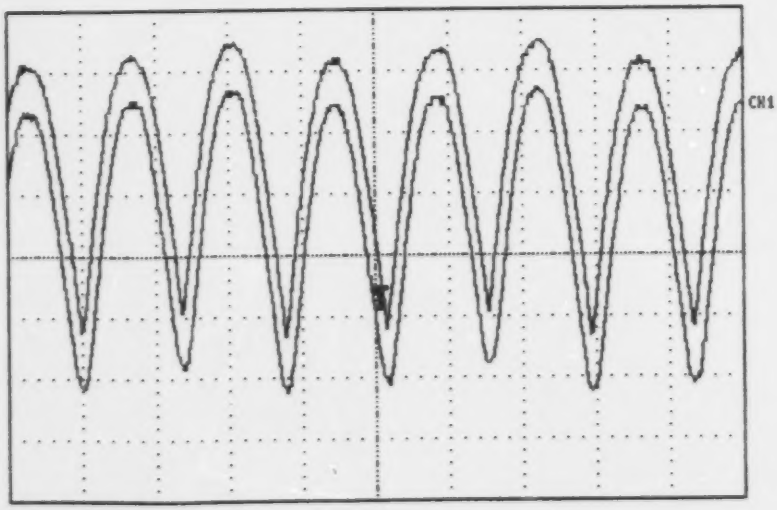
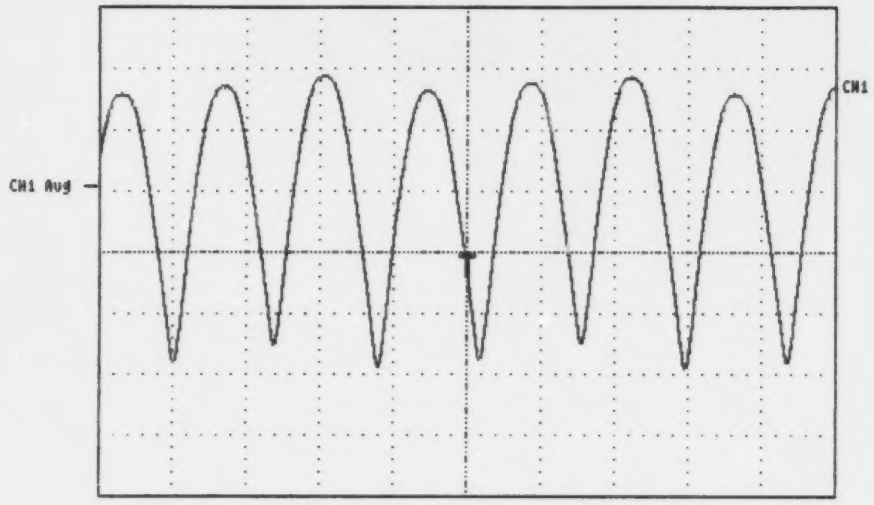


Figure C31 Light intensty @ 150 A. (18 in. up; 33 in. right)

CH1 2 mVΩ (Avg 16.2 mV, Max 19.9 mV, Min 10.3 mV, Rip 59.1%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mVΩ (Maxima(7): δMax 2.56 mV(15.8%), δAvg 2.32 mV(14.3%))
(Minima(7): δMax 2.40 mV(14.8%), δAvg 2.26 mV(13.9%))
A 2 ms 50.30 V LINE Env:256

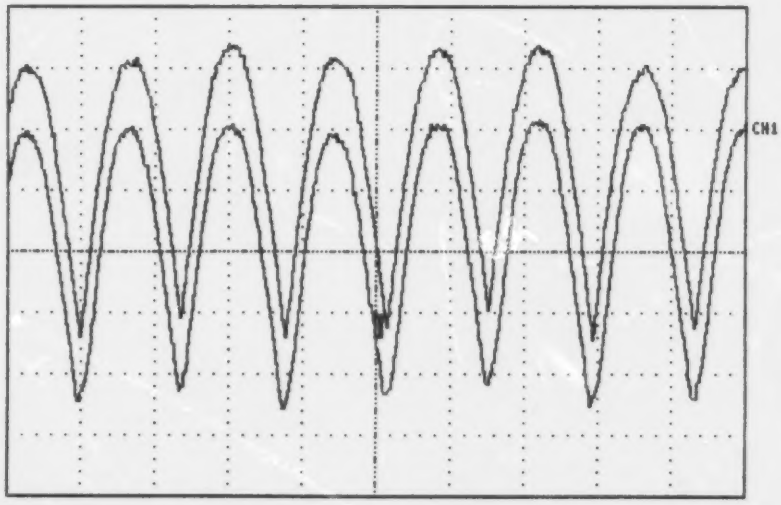
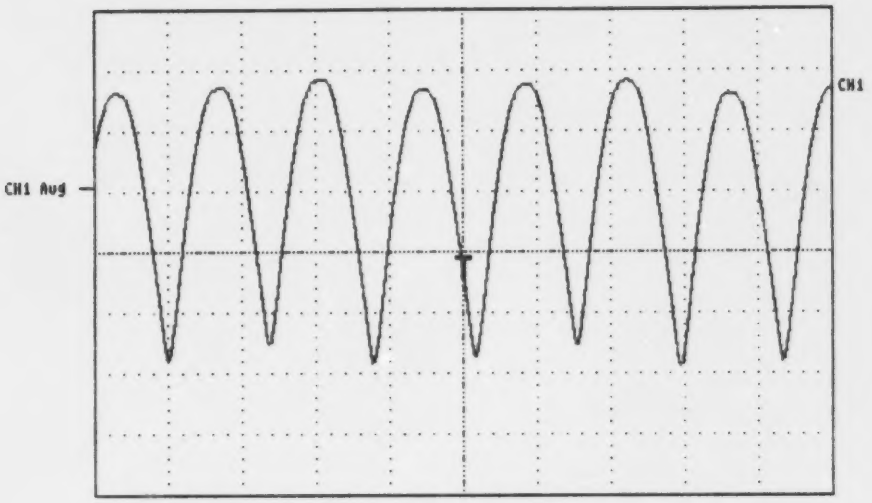


Figure C32 Light intensty @ 150 A. (18 in. up; 46 in. right)

CH1 2 mVΩ (Avg 16.3 mV, Max 19.8 mV, Min 18.3 mV, Rip 58.1%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mVΩ (Maxima(7): δMax 1.92 mV(11.8%), δAvg 1.71 mV(10.5%))
(Minima(7): δMax 2.08 mV(12.8%), δAvg 1.93 mV(11.9%))
A 2 ms 50.30 V LINE Env:256

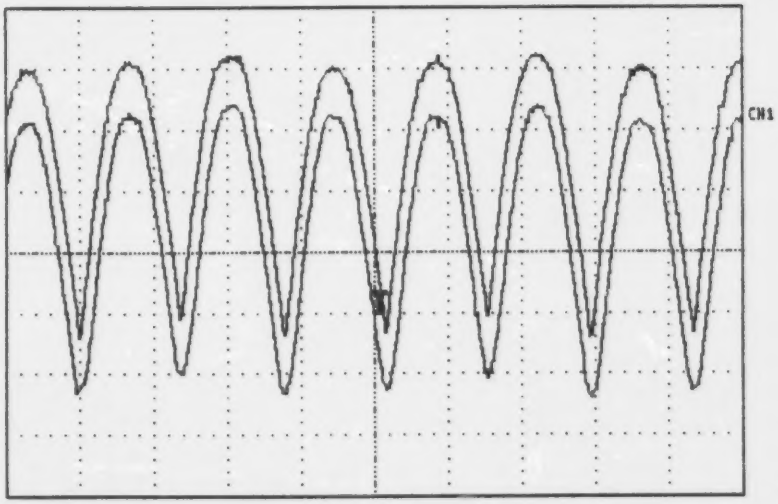
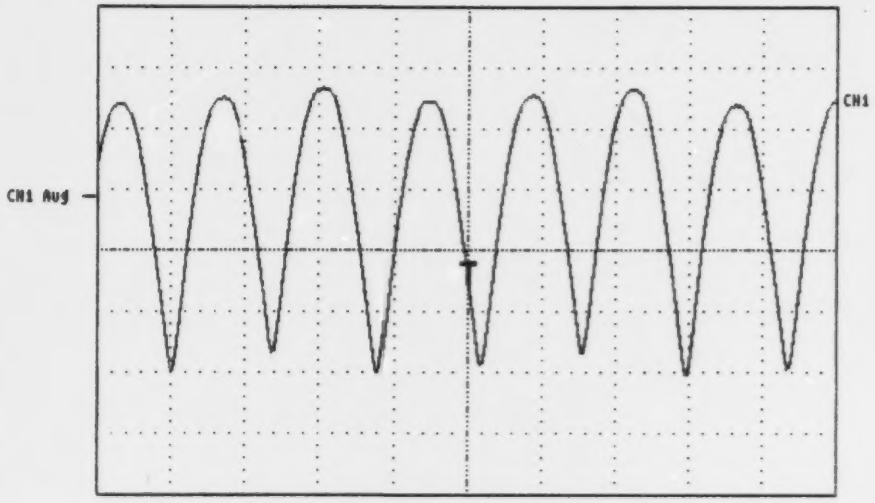


Figure C33 Light intensty @ 150 A. (12 in. up; 46 in. right)

CH1 2 mVΩ (Avg 15.9 mV, Max 19.5 mV, Min 10.8 mV, Rip 59.5%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mVΩ (Maxima(7): δMax 1.84 mV(11.6%), δAvg 1.70 mV(10.7%))
(Minima(7): δMax 2.32 mV(14.6%), δAvg 2.08 mV(13.1%))
A 2 ms 50.30 V LINE Env:256

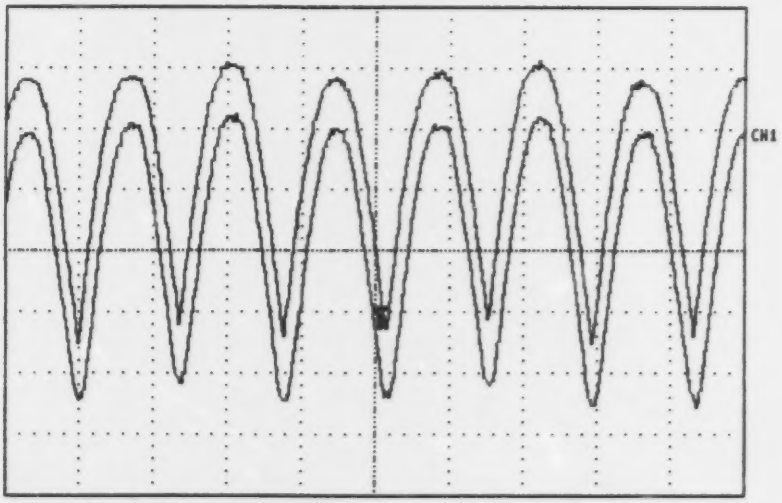
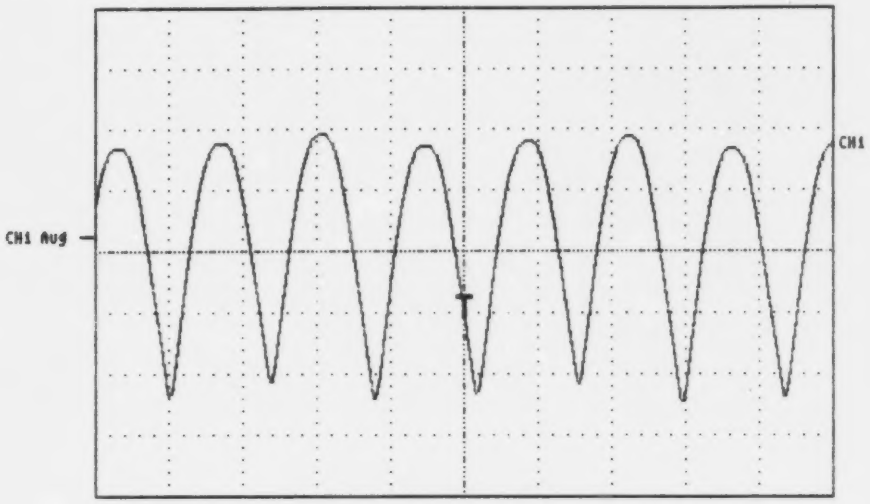


Figure C34 Light intensty @ 150 A. (6 in. up; 46 in. right)

CH1 2 mVΩ (Avg 14.6 mV, Max 17.9 mV, Min 9.22 mV, Rip 59.7%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mVΩ (Maxima(7): δMax 1.84 mV(12.6%), δAvg 1.74 mV(11.9%))
(Minima(7): δMax 2.00 mV(13.7%), δAvg 1.82 mV(12.4%))
A 2 ms 50.30 V LINE Env:256

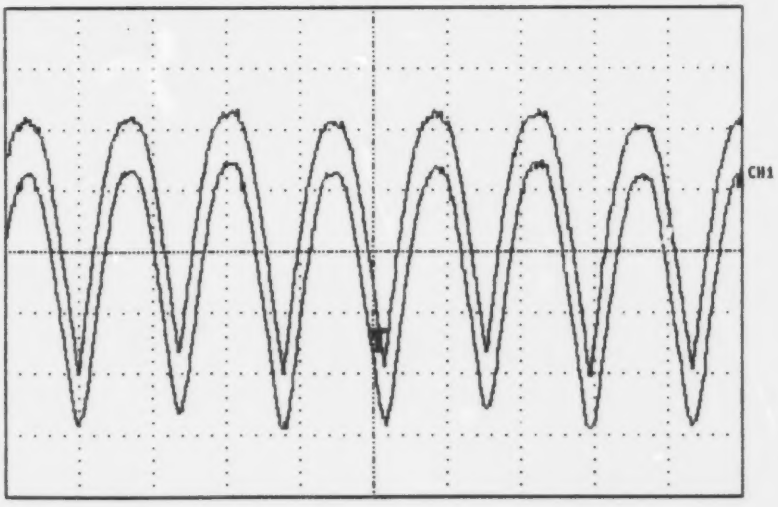
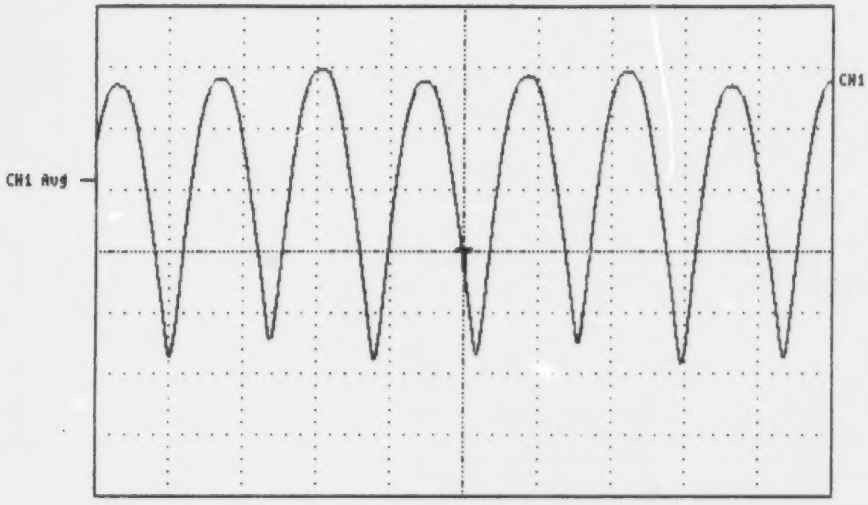


Figure C35 Light intensty @ 150 A. (24 in. up; 46 in. right)

CH1 2 mVΩ (Avg 16.4 mV, Max 20.0 mV, Min 10.4 mV, Rip 58.4%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mVΩ (Maxima(7): δMax 1.76 mV(10.7%), δAvg 1.53 mV(9.3%))
(Minima(7): δMax 1.92 mV(11.7%), δAvg 1.74 mV(10.6%))
A 2 ms 50.30 V LINE Env:256

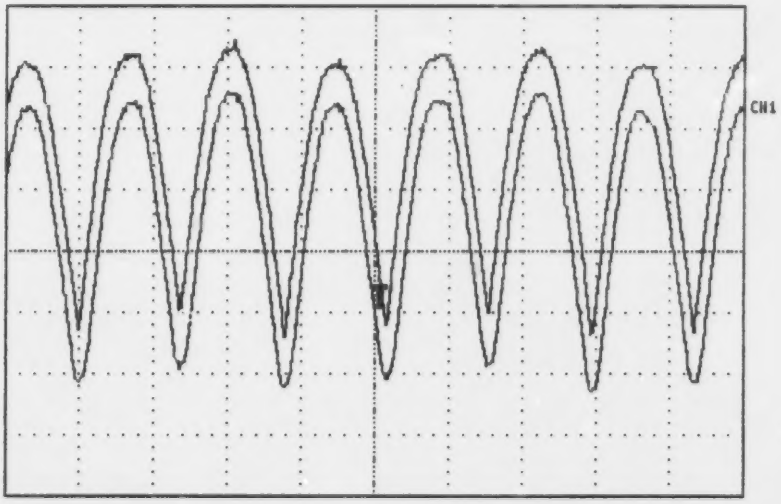
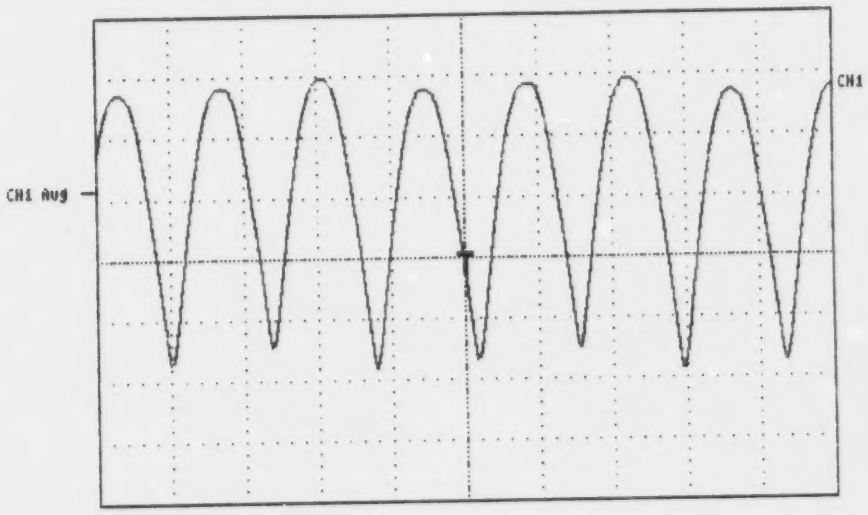
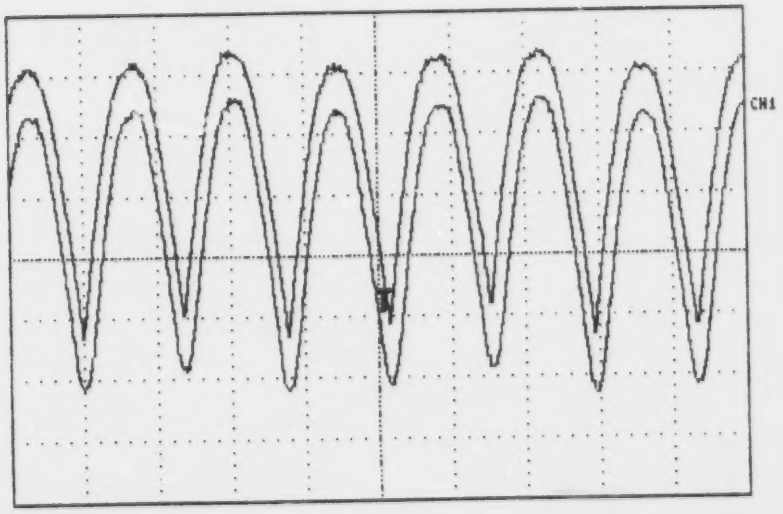


Figure C36 Light intensty @ 150 A. (24 in. up; 46 in. right)

CH1 2 mVΩ (Avg 16.4 mV, Max 20.0 mV, Min 10.4 mV, Rip 58.4%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mVΩ (Maxima(7): δMax 1.68 mV(10.2%), δAvg 1.58 mV(9.6%))
(Minima(7): δMax 2.00 mV(12.7%), δAvg 1.90 mV(11.6%))
A 2 ms 50.30 V LINE Env:256



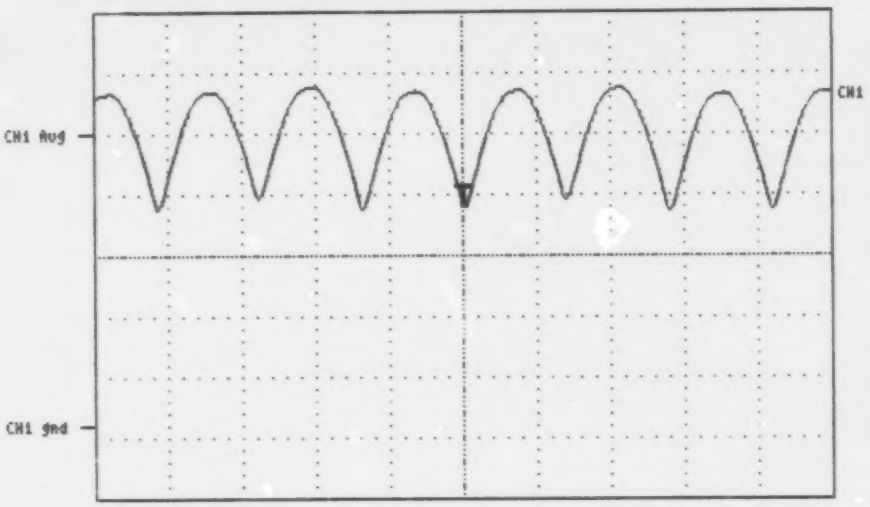
APPENDIX C

Table C3. Summary of data for the arc intensity at 200 Amps.

Figure (#)	Position to center right (in.)	up (in.)	Ripple (%)	Maxima max. (%)	Maxima avg. (%)	Minima max. (%)	Minima avg. (%)
C37	0	6	42.2	8.3	7.6	9.9	8.7
C38	0	18	41.0	7.0	6.8	9.3	8.2
C39	-12	18	41.2	8.9	8.5	9.7	9.3
C40	-26	18	41.5	7.3	6.8	8.9	7.9
C41	-37	18	41.4	6.6	5.9	8.3	7.9
C42	-49	18	41.7	7.7	6.8	8.5	7.7
C43	-57	18	40.9	8.9	7.5	9.8	8.4
C44	-57	12	41.5	8.1	7.4	9.9	8.9
C45	-57	6	44.4	6.6	6.1	8.5	8.4
C46	-57	24	43.3	7.1	6.2	8.8	8.2
C47	13	18	43.2	7.3	6.5	8.2	7.7
C48	25	18	44.2	6.5	5.8	6.5	6.2
C49	33	18	43.7	5.9	5.3	6.7	5.5
C50	46	18	45.9	7.5	6.9	7.5	6.6
C51	46	12	45.9	6.7	5.6	6.7	6.0
C52	46	6	46.4	8.0	6.5	7.1	6.6
C53	46	24	45.0	5.8	5.4	5.8	5.0
C54	46	24	45.0	6.7	5.7	5.8	5.2
Average			43.24	7.27	6.52	8.11	7.36
Std. Dev.			1.83	0.89	0.84	1.36	1.30

Figure C37 Light intensty @ 200 A. (6 in. up; center)

CH1 5 mVΩ (Avg 24.2 mV, Max 27.9 mV, Min 17.7 mV, Rip 42.2%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(6): δMax 2.00 mV(8.3%), δAvg 1.83 mV(7.6%))
(Minima(7): δMax 2.40 mV(9.9%), δAvg 2.11 mV(8.7%))
A 2 ms 50.30 V LINE Env:256

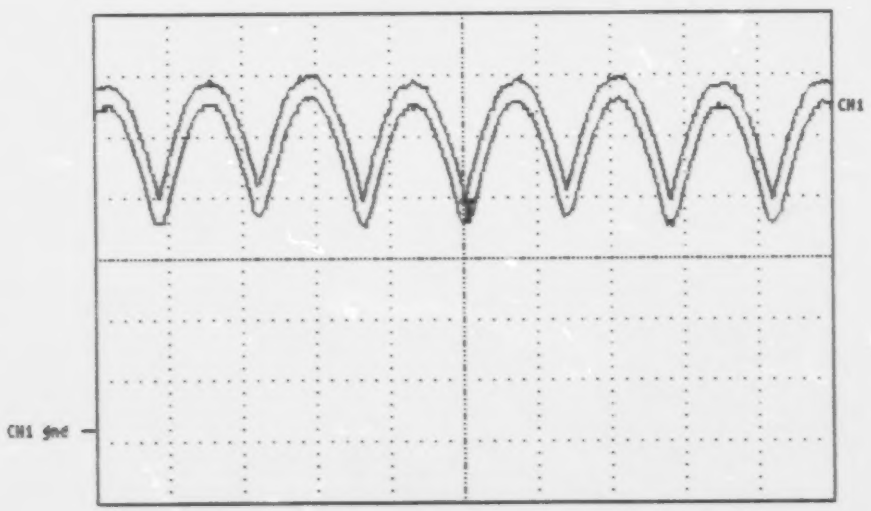
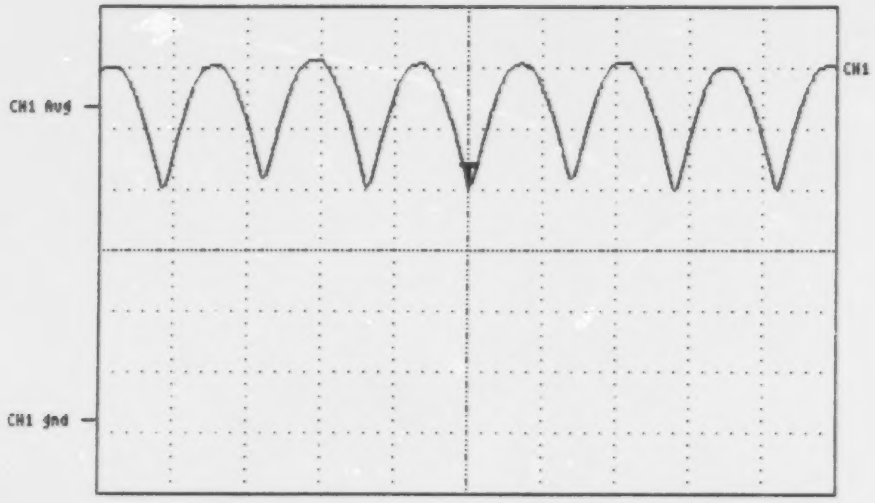


Figure C38 Light intensty @ 200 A. (18 in. up; center)

CH1 5 mVΩ (Avg 25.8 mV, Max 29.7 mV, Min 19.1 mV, Rip 41.0%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(6): δMax 1.80 mV(7.8%), δAvg 1.77 mV(6.8%))
(Minima(7): δMax 2.40 mV(9.3%), δAvg 2.11 mV(8.2%))
A 2 ms 50.30 V LINE Env:256

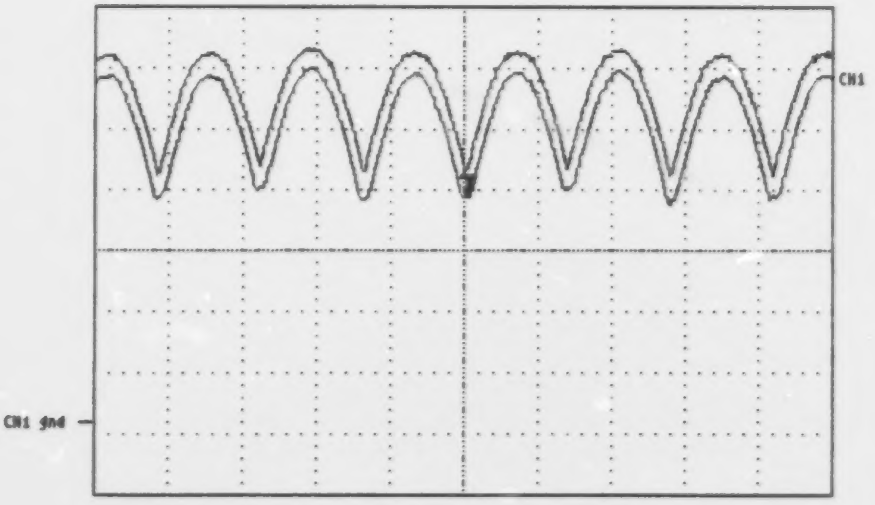
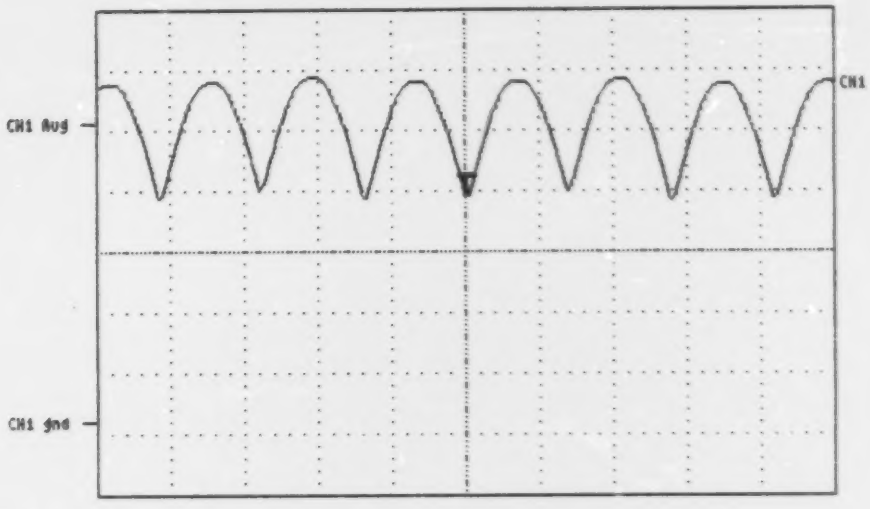


Figure C39 Light intensty @ 200 A. (18 in. up; 12 in. left)

CH1 5 mVΩ (Avg 24.8 mV, Max 28.5 mV, Min 18.3 mV, Rip 41.2%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(6): δMax 2.20 mV(8.9%), δAvg 2.10 mV(8.5%))
(Minima(7): δMax 2.40 mV(9.7%), δAvg 2.31 mV(9.3%))
A 2 ms 50.30 V LINE Env:256

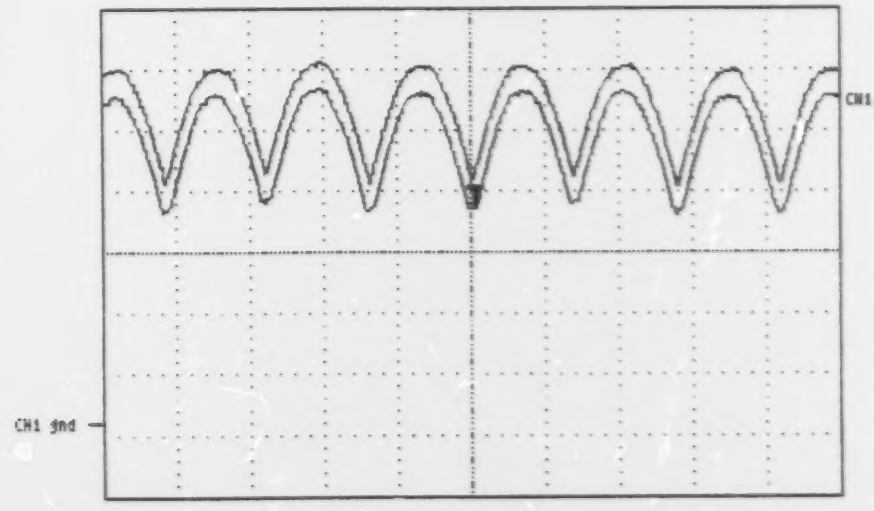
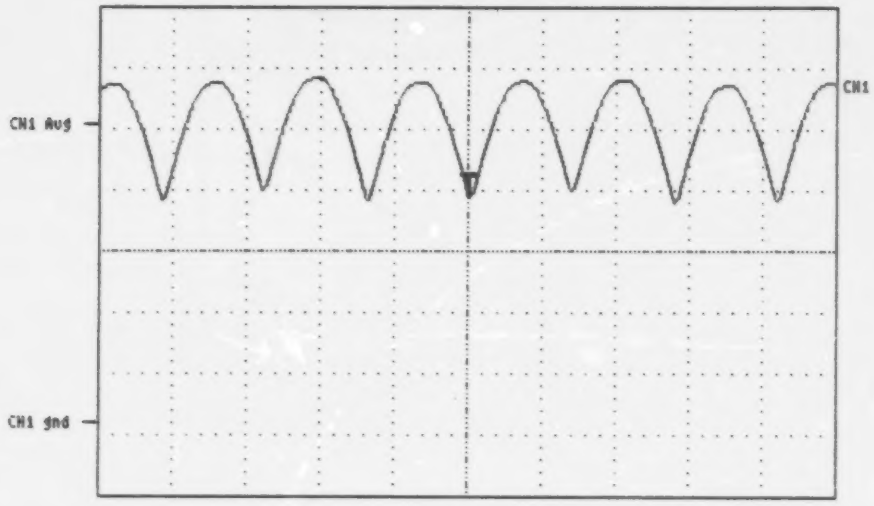


Figure C40 Light intensty @ 200 A. (18 in. up; 26 in. left)

CH1 5 mVΩ (Avg 24.6 mV, Max 28.3 mV, Min 18.1 mV, Rip 41.5%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(6): δMax 1.88 mV(7.3%), δAvg 1.67 mV(6.8%))
(Minima(7): δMax 2.20 mV(8.9%), δAvg 1.94 mV(7.9%))
A 2 ms 50.30 V LINE Env:256

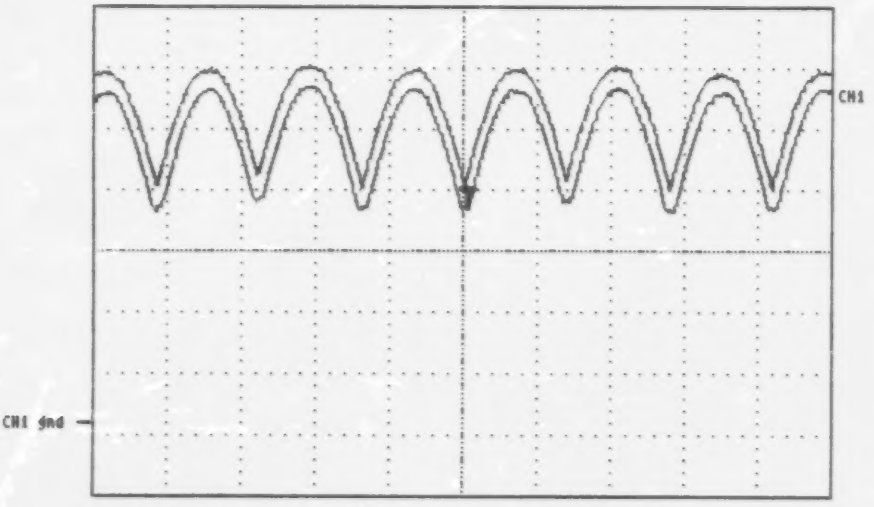
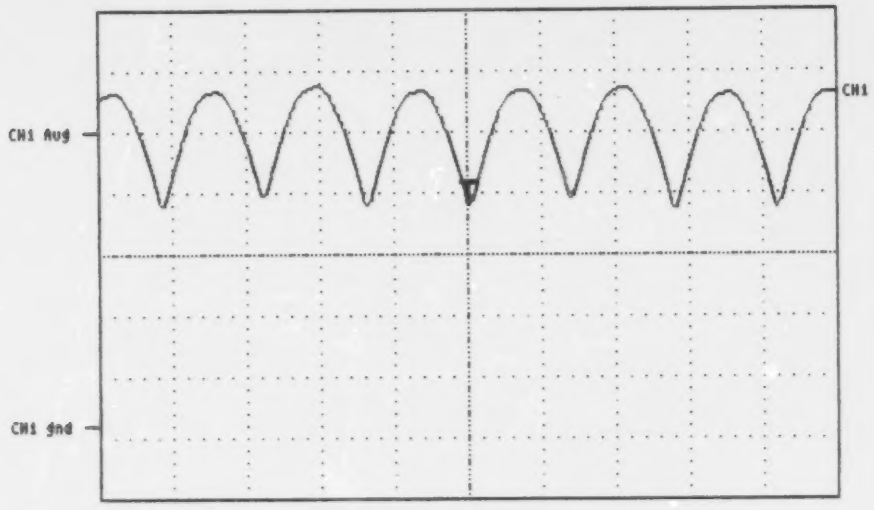


Figure C41 Light intensty @ 200 A. (18 in. up; 37 in. left)

CH1 5 mVΩ (Avg 24.1 mV, Max 27.9 mV, Min 17.9 mV, Rip 41.4%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(6): δMax 1.60 mV(6.6%), δAvg 1.43 mV(5.9%))
(Minima(7): δMax 2.00 mV(8.3%), δAvg 1.91 mV(7.9%))
A 2 ms 50.30 V LINE Env:256

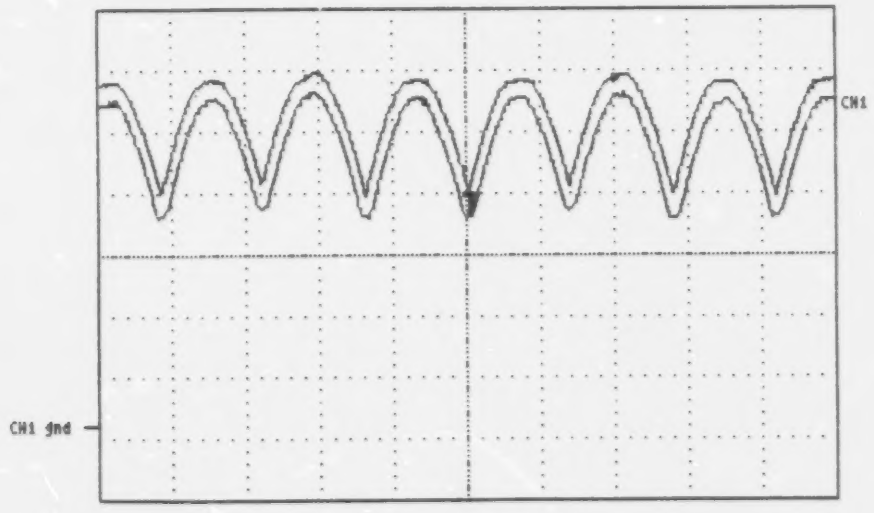
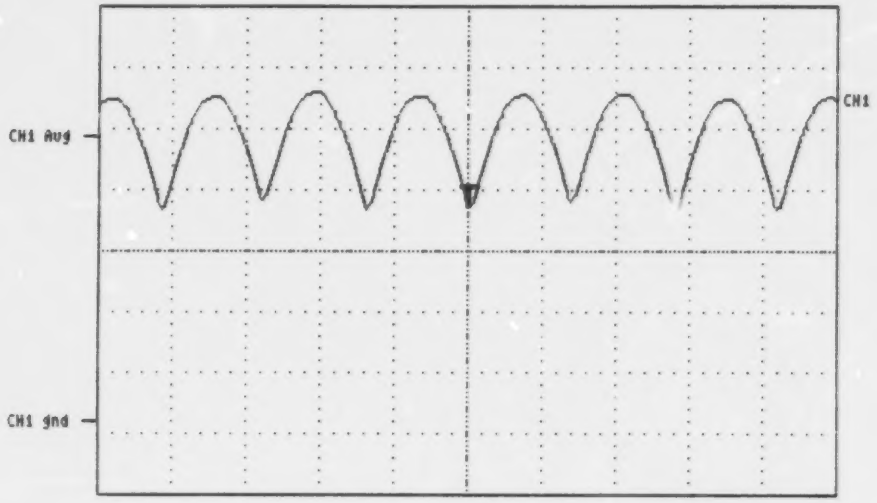


Figure C42 Light intensty @ 200 A. (18 in. up; 49 in. left)

CH1 5 mVΩ (Avg 23.5 mV, Max 27.1 mV, Min 17.3 mV, Rip 41.7%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(6): δMax 1.80 mV(7.7%), δAvg 1.60 mV(6.8%))
(Minima(7): δMax 2.00 mV(8.5%), δAvg 1.80 mV(7.7%))
A 2 ms 50.30 V LINE Env:256

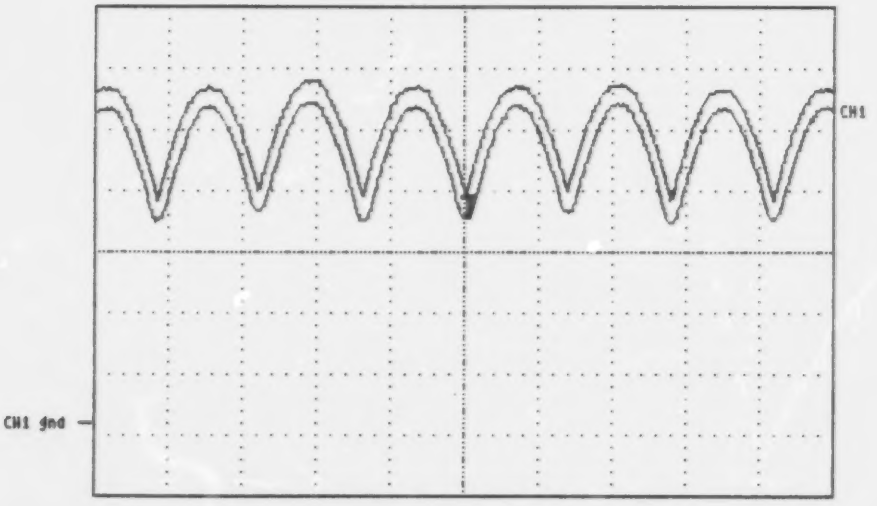
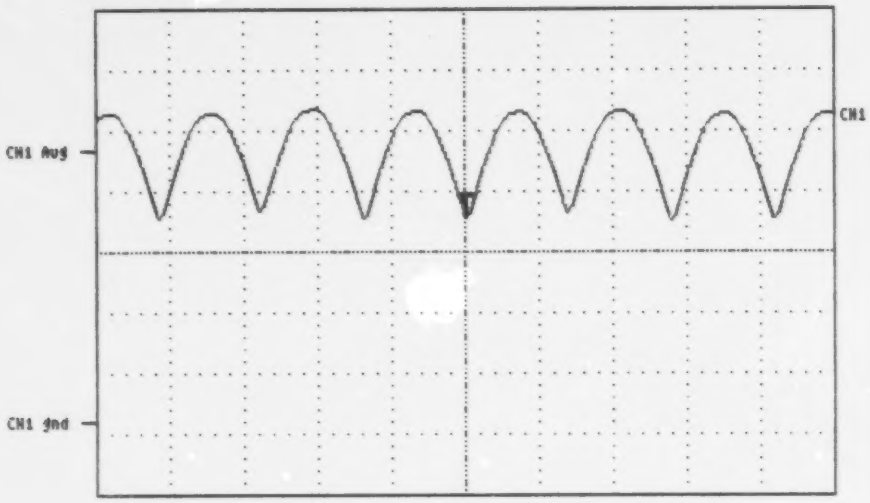


Figure C43 Light intensty @ 200 A. (18 in. up; 57 in. left)

CH1 5 mVΩ (Avg 22.5 mV, Max 25.9 mV, Min 16.7 mV, Rip 40.9%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(7): δMax 2.00 mV(8.9%), δAvg 1.69 mV(7.5%))
(Minima(7): δMax 2.20 mV(9.8%), δAvg 1.89 mV(8.4%))
A 2 ms 50.30 V LINE Env:256

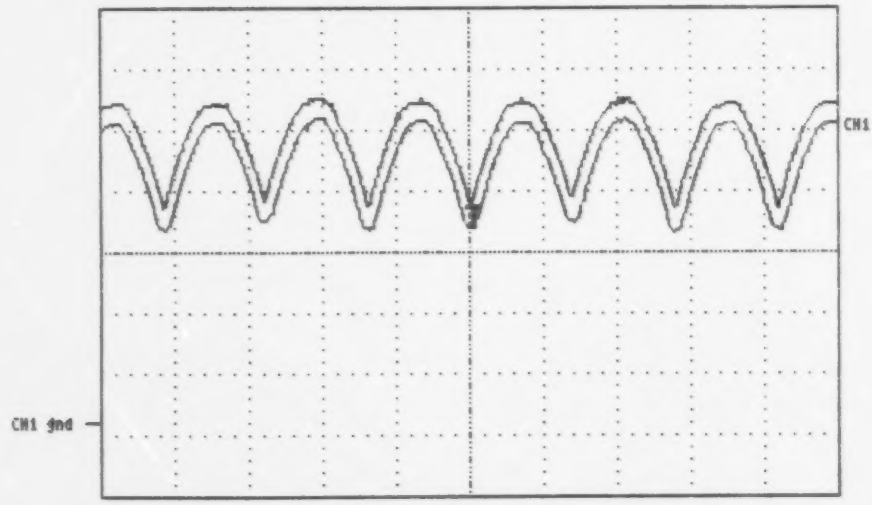
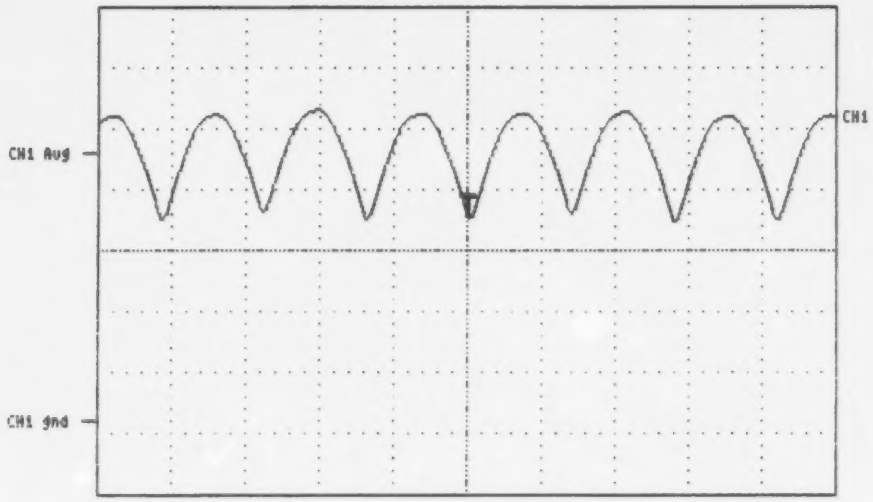


Figure C44 Light intensty @ 200 A. (12 in. up; 57 in. left)

CH1 5 mVΩ (Avg 22.2 mV, Max 25.7 mV, Min 16.5 mV, Rip 41.5%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(6): δMax 1.80 mV(8.1%), δAvg 1.63 mV(7.4%))
(Minima(7): δMax 2.20 mV(9.9%), δAvg 1.97 mV(8.9%))
A 2 ms 50.30 V LINE Env:256

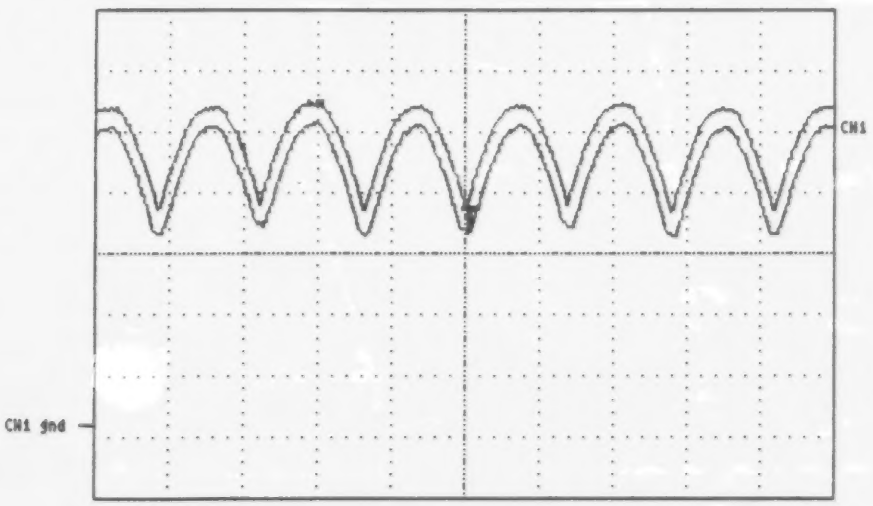
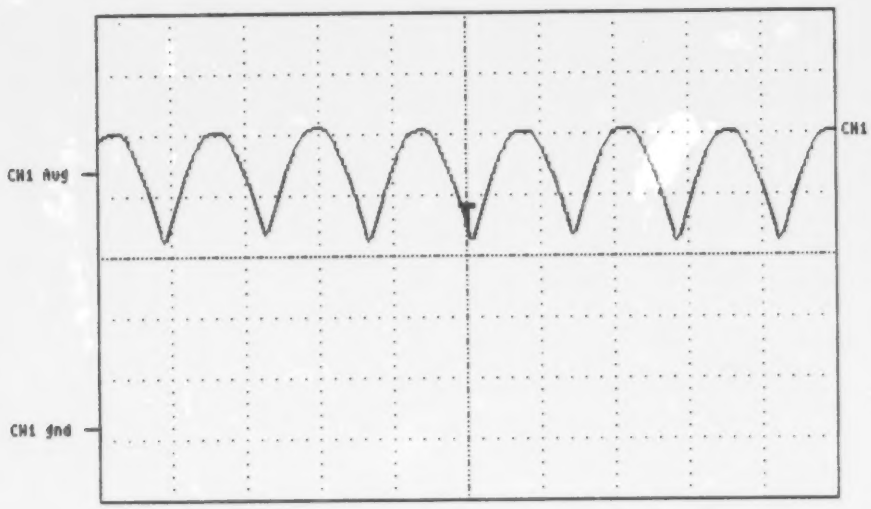


Figure C45 Light intensty @ 200 A. (6 in. up; 57 in. left)

CH1 5 mVΩ (Avg 21.2 mV, Max 24.7 mV, Min 15.3 mV, Rip 44.4%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(7): δMax 1.40 mV(6.6%), δAvg 1.29 mV(6.1%))
(Minima(7): δMax 1.80 mV(8.5%), δAvg 1.77 mV(8.4%))
A 2 ms 50.30 V LINE Env:256

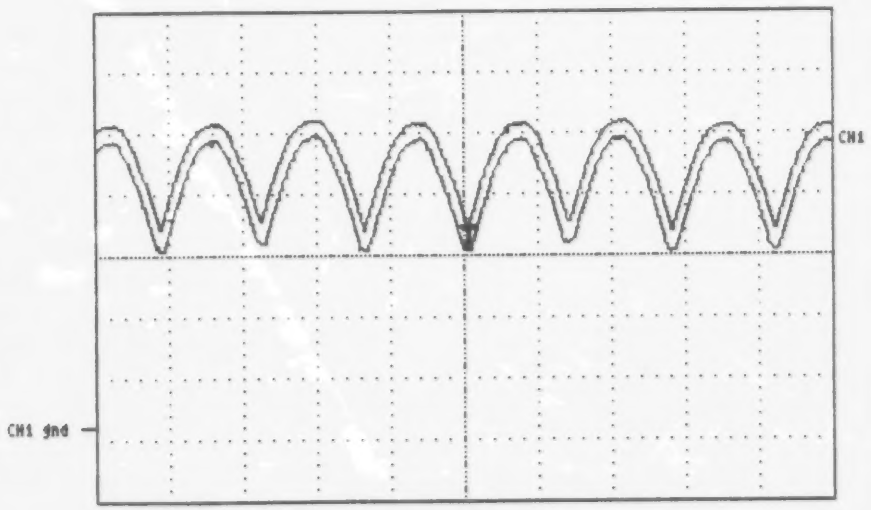
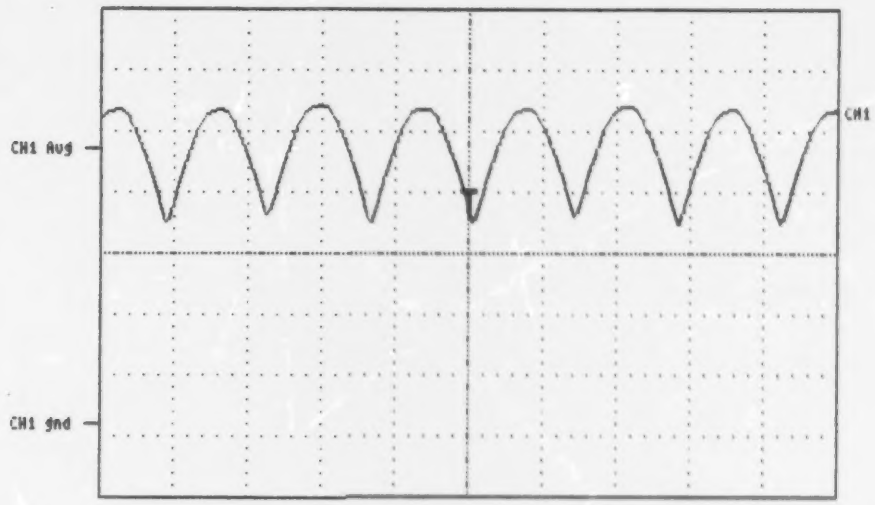


Figure C46 Light intensty @ 200 A. (24 in. up; 57 in. left)

CH1 5 mVΩ (Avg 22.6 mV, Max 26.3 mV, Min 16.5 mV, Rip 43.3%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(7): δMax 1.60 mV(7.1%), δAvg 1.40 mV(6.2%))
(Minima(7): δMax 2.00 mV(8.8%), δAvg 1.86 mV(8.2%))
A 2 ms 50.30 V LINE Env:256

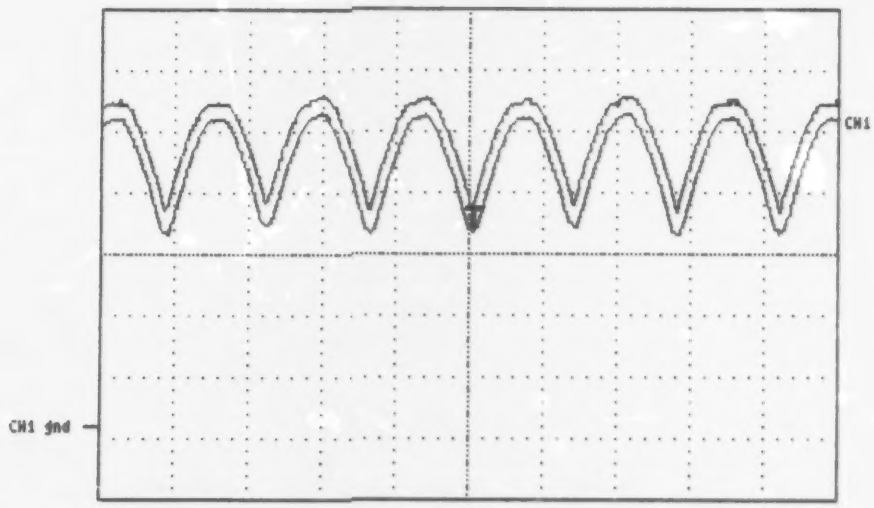
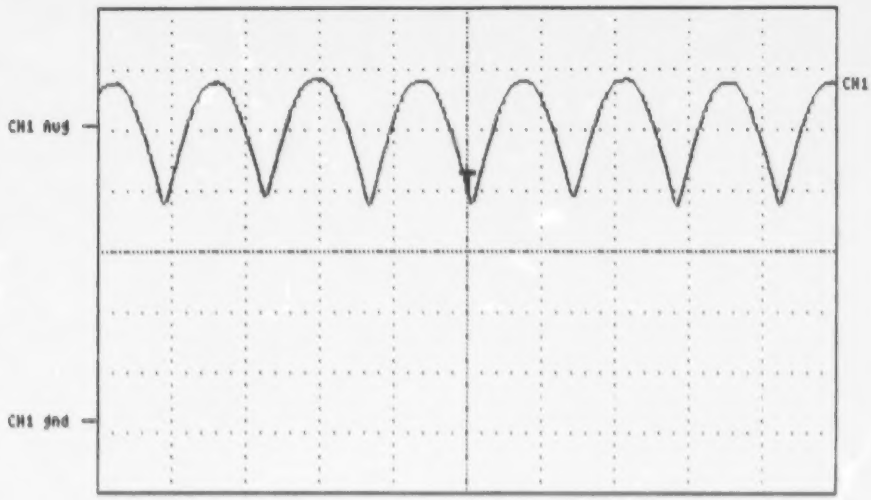


Figure C47 Light intensty @ 200 A. (18 in. up; 13 in. right)

CH1 5 mVΩ (Avg 24.5 mV, Max 28.5 mV, Min 17.9 mV, Rip 43.2%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(6): δMax 1.80 mV(7.3%), δAvg 1.60 mV(6.5%))
(Minima(7): δMax 2.80 mV(8.2%), δAvg 1.89 mV(7.7%))
A 2 ms 50.30 V LINE Env:256

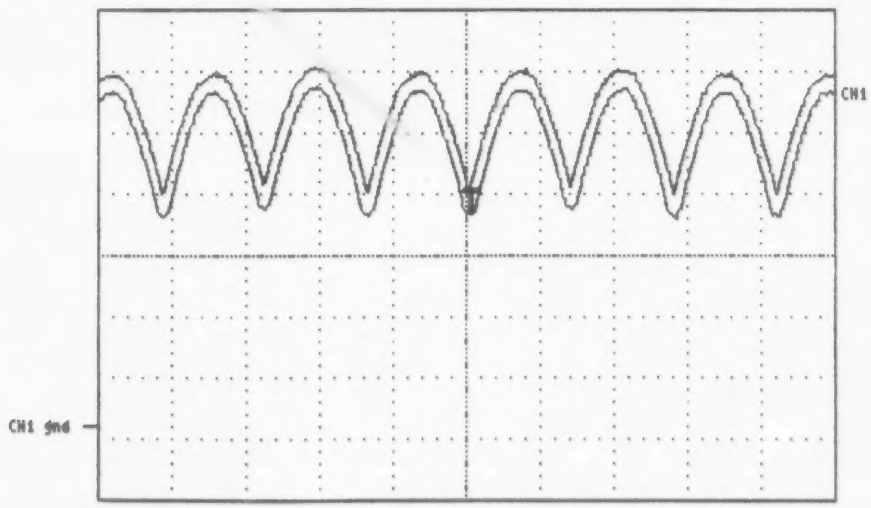
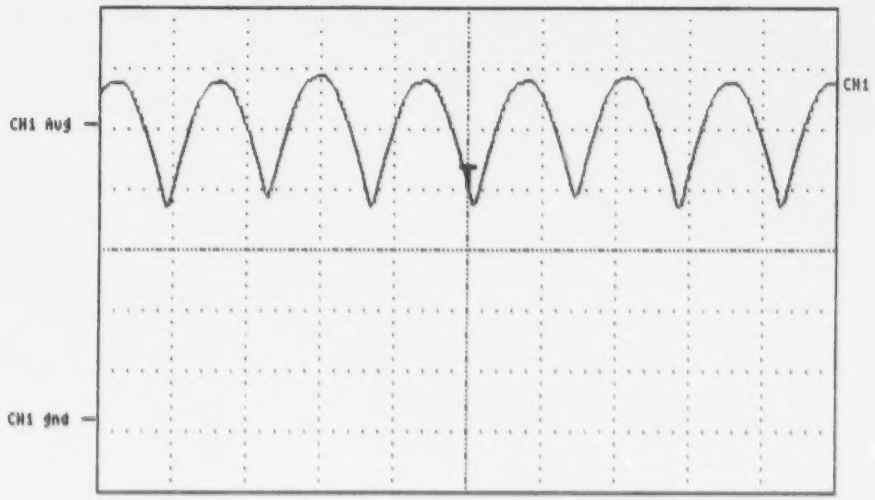


Figure C48 Light intensty @ 200 A. (18 in. up; 25 in. right)

CH1 5 mVΩ (Avg 24.4 mV, Max 28.5 mV, Min 17.7 mV, Rip 44.2%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(7): δMax 1.60 mV(6.5%), δAvg 1.43 mV(5.8%))
(Minima(7): δMax 1.60 mV(6.5%), δAvg 1.51 mV(6.2%))
A 2 ms 50.30 V LINE Env:256

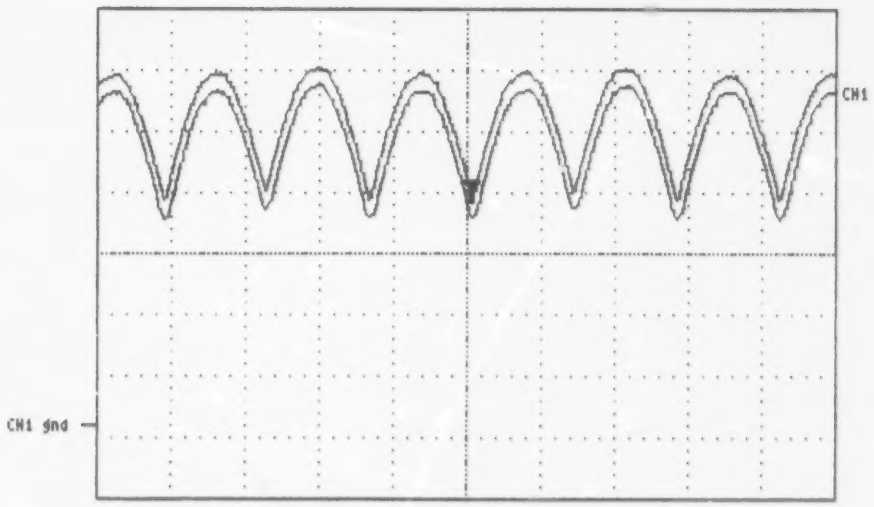
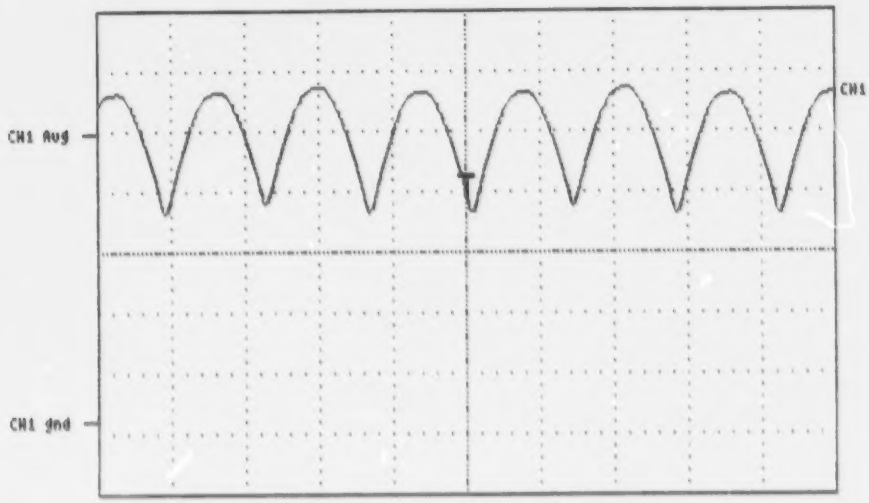


Figure C49 Light intensty @ 200 A. (18 in. up; 33 in. right)

CH1 5 mVΩ (Avg 23.8 mV, Max 27.7 mV, Min 17.3 mV, Rip 43.7%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(7): δMax 1.48 mV(5.9%), δAvg 1.26 mV(5.3%))
(Minima(7): δMax 1.60 mV(6.7%), δAvg 1.31 mV(5.5%))
A 2 ms 50.30 V LINE Env:256

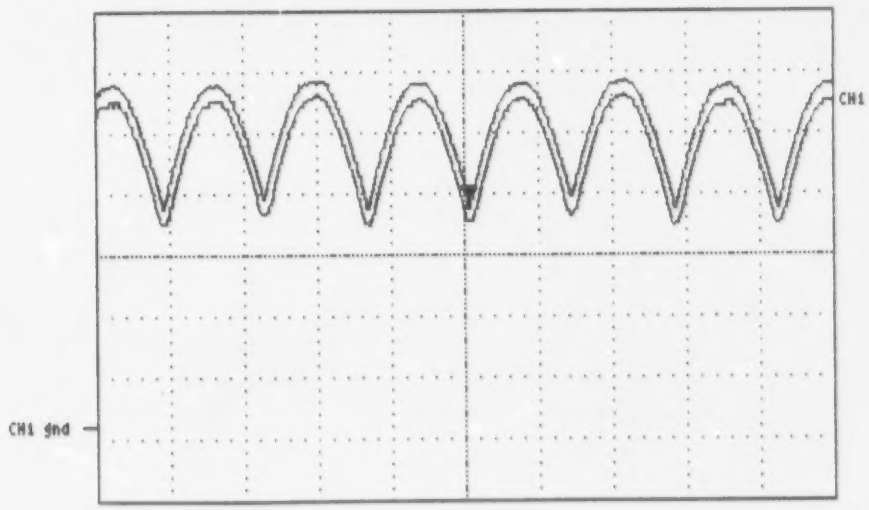
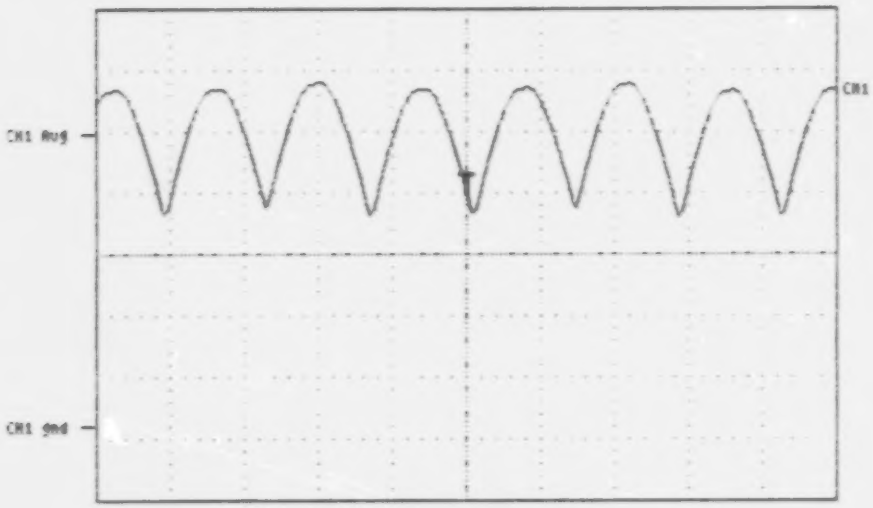


Figure C58 Light intensty @ 200 A. (18 in. up; 46 in. right)

CH1 5 mVΩ (Avg 24.0 mV, Max 28.1 mV, Min 17.1 mV, Rip 45.9%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(7): δMax 1.80 mV(7.5%), δAvg 1.66 mV(6.9%))
(Minima(7): δMax 1.80 mV(7.5%), δAvg 1.57 mV(6.6%))
A 2 ms 50.30 V LINE Env:256

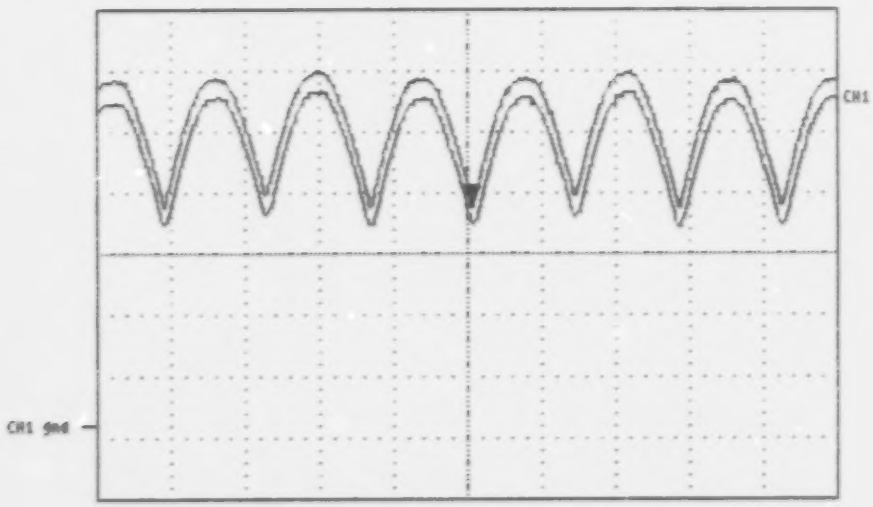
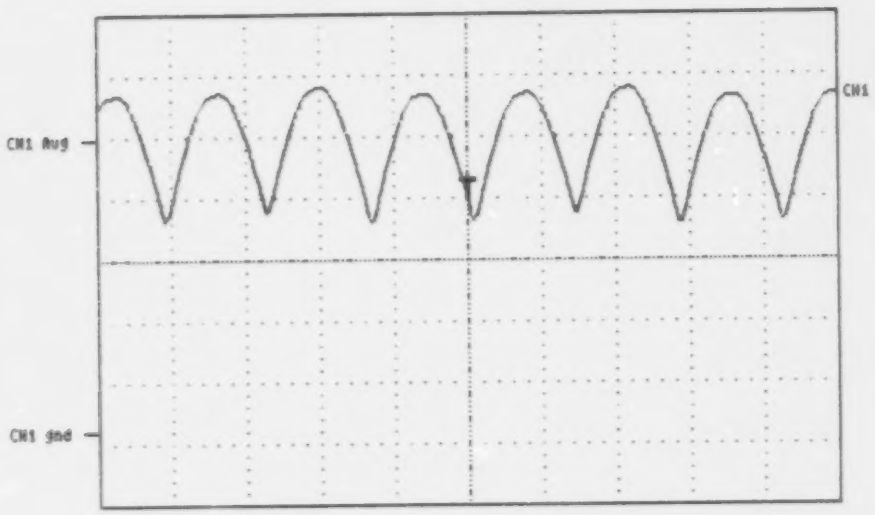


Figure C51 Light intensty @ 200 A. (12 in. up; 46 in. right)

CH1 5 mVΩ (Avg 23.9 mV, Max 28.1 mV, Min 17.1 mV, Rip 45.9%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(7): δMax 1.60 mV(6.7%), δAvg 1.34 mV(5.6%))
(Minima(7): δMax 1.60 mV(6.7%), δAvg 1.43 mV(6.0%))
A 2 ms 50.30 V LINE Env:256

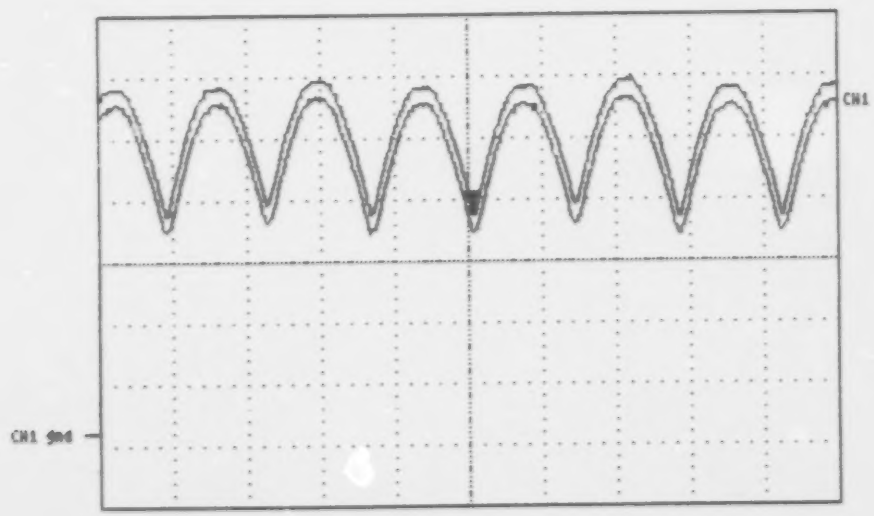
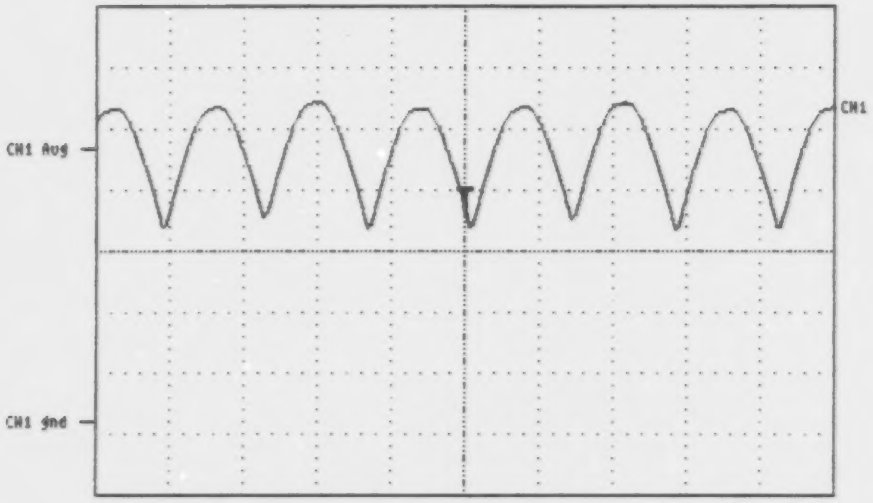


Figure C52 Light intensty @ 200 A. (6 in. up; 46 in. right)

CH1 5 mVΩ (Avg 22.4 mV, Max 26.3 mV, Min 15.9 mV, Rip 46.4%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(7): δMax 1.80 mV(8.0%), δAvg 1.46 mV(6.5%))
(Minima(7): δMax 1.60 mV(7.1%), δAvg 1.49 mV(6.6%))
A 2 ms 50.30 V LINE Env:256

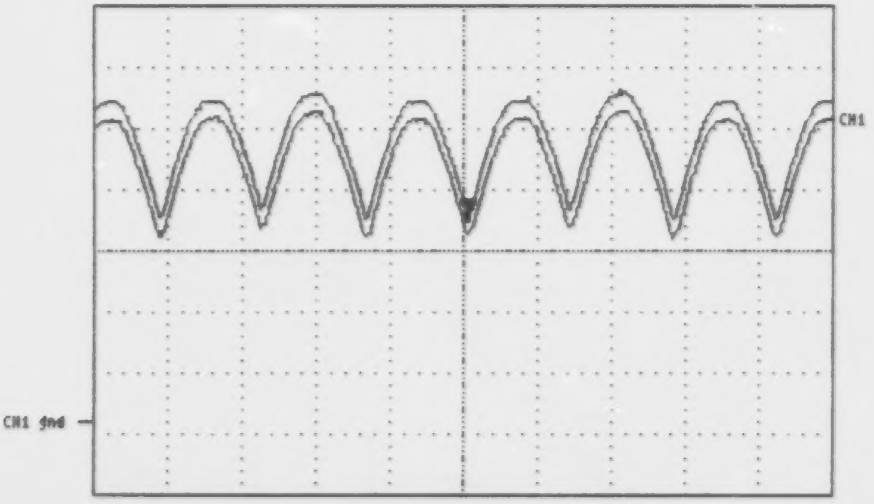
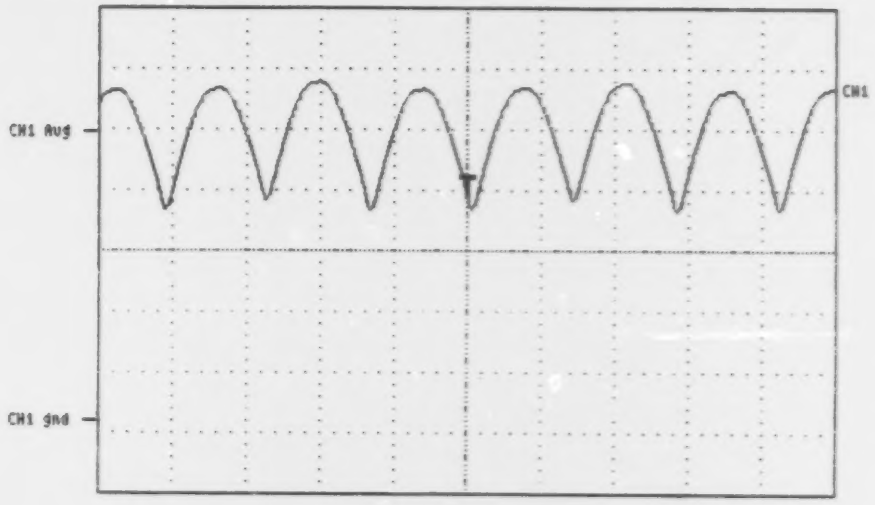


Figure C53 Light intensty @ 200 A. (24 in. up; 46 in. right)

CH1 5 mVΩ (Avg 24.0 mV, Max 28.1 mV, Min 17.3 mV, Rip 45.0%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(6): δMax 1.40 mV(5.8%), δAvg 1.30 mV(5.4%))
(Minima(7): δMax 1.40 mV(5.8%), δAvg 1.20 mV(5.0%))
A 2 ms 50.30 V LINE Env:256

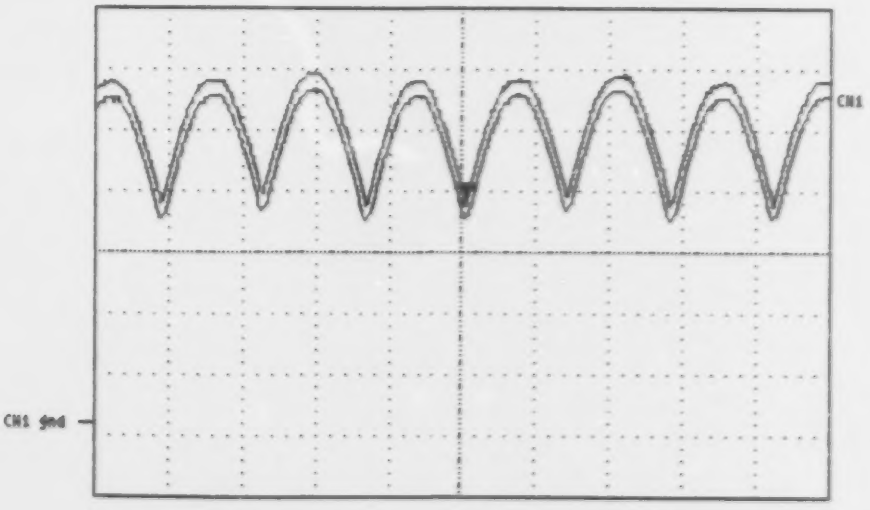
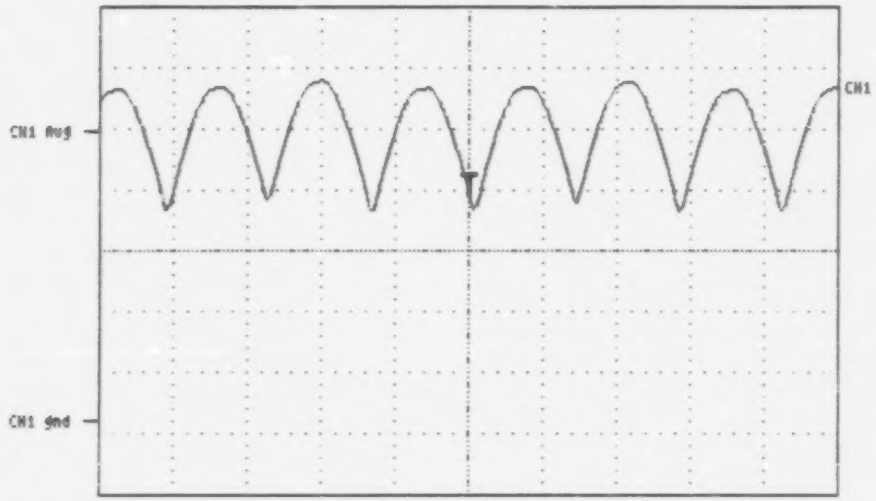
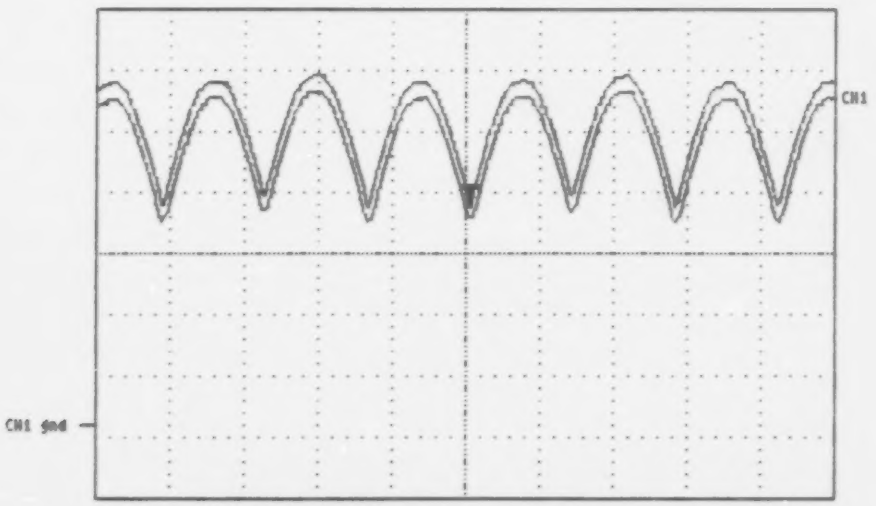


Figure C54 Light intensty @ 200 A. (24 in. up; 46 in. right)

CH1 5 mVΩ (Avg 24.0 mV, Max 28.1 mV, Min 17.3 mV, Rip 45.0%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(7): δMax 1.60 mV(6.7%), δAvg 1.37 mV(5.7%))
(Minima(7): δMax 1.40 mV(5.8%), δAvg 1.26 mV(5.2%))
A 2 ms 50.30 V LINE Env:256



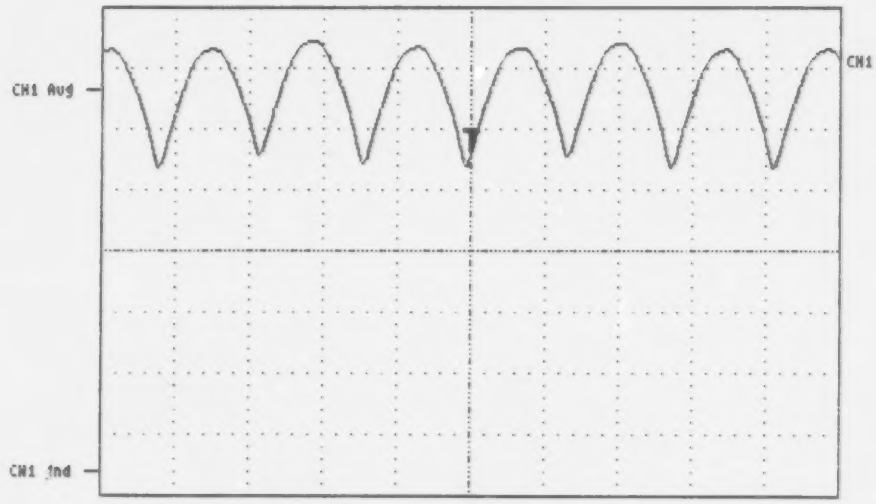
APPENDIX C

Table C4. Summary of data for the arc intensity at 239 Amps.

Figure (#)	Position to center right (in.)	up (in.)	Ripple (%)	Maxima max. (%)	Maxima avg. (%)	Minima max. (%)	Minima avg. (%)
C55	0	6	33.3	6.4	5.8	5.8	5.3
C56	0	18	32.5	7.8	7.1	8.4	7.2
C57	-12	18	33.3	5.3	4.8	5.3	4.7
C58	-26	18	32.5	5.1	4.8	5.7	4.9
C59	-37	18	33.2	5.9	5.2	6.5	5.5
C60	-49	18	33.6	6.0	5.4	5.4	5.2
C61	-57	18	32.9	6.2	5.7	6.2	5.6
C62	-57	12	33.1	6.2	5.8	6.2	5.5
C63	-57	6	34.5	7.2	6.0	6.5	5.9
C64	-57	24	33.3	6.2	5.5	6.2	5.4
C65	13	18	32.5	5.7	5.3	5.7	5.5
C66	25	18	32.6	5.2	4.9	6.5	5.9
C67	33	18	33.6	5.3	5.2	5.9	5.5
C68	46	18	33.1	5.3	5.1	6.0	5.4
C69	46	12	33.8	6.0	5.2	6.6	5.6
C70	46	6	33.5	6.1	5.7	6.1	5.5
C71	46	24	32.6	5.3	4.8	6.0	5.3
C72	46	24	32.7	8.0	5.6	9.3	5.6
Average			33.14	6.07	5.44	6.35	5.53
Std. Dev.			0.53	0.83	0.54	0.97	0.50

Figure C55 Light intensty @ 239 A. (6 in. up; center)

CH1 5 mVΩ (Avg 31.2 mV, Max 35.1 mV, Min 24.7 mV, Rip 33.3%)
A 2 ms 50.30 V LINE Avg:256



CH1 5 mVΩ (Maxima(6): δMax 2.00 mV(6.4%), δAvg 1.80 mV(5.8%))
(Minima(7): δMax 1.80 mV(5.8%), δAvg 1.66 mV(5.3%))
A 2 ms 50.30 V LINE Env:256

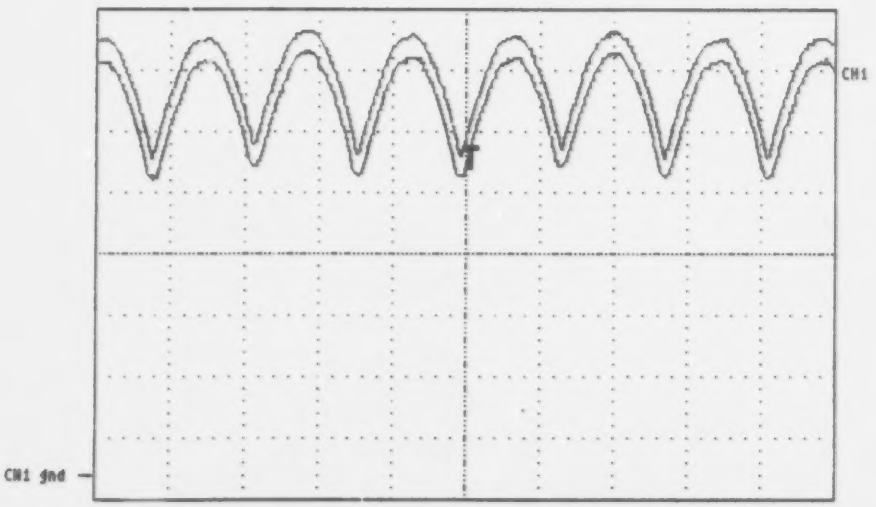
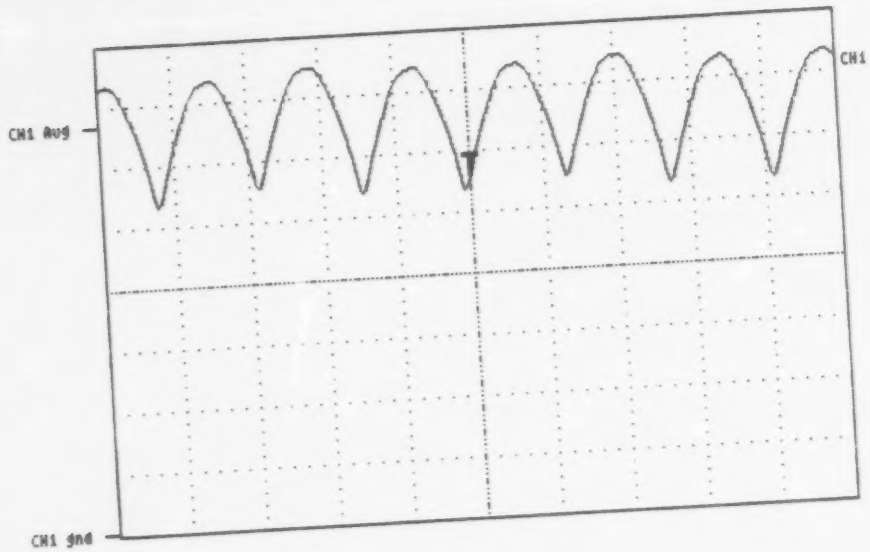


Figure C56 Light intensty @ 239 A. (18 in. up; center)

CH1 5 mVΩ (Avg 33.2 mV, Max 37.3 mV, Min 26.4 mV, Rip 32.5%)
A 2 ms 50.30 V LINE Avg:256



CH1 5 mVΩ (Maxima(6): δMax 2.60 mV(7.8%), δAvg 2.37 mV(7.1%))
(Minima(7): δMax 2.80 mV(8.4%), δAvg 2.40 mV(7.2%))
A 2 ms 50.30 V LINE Env:256

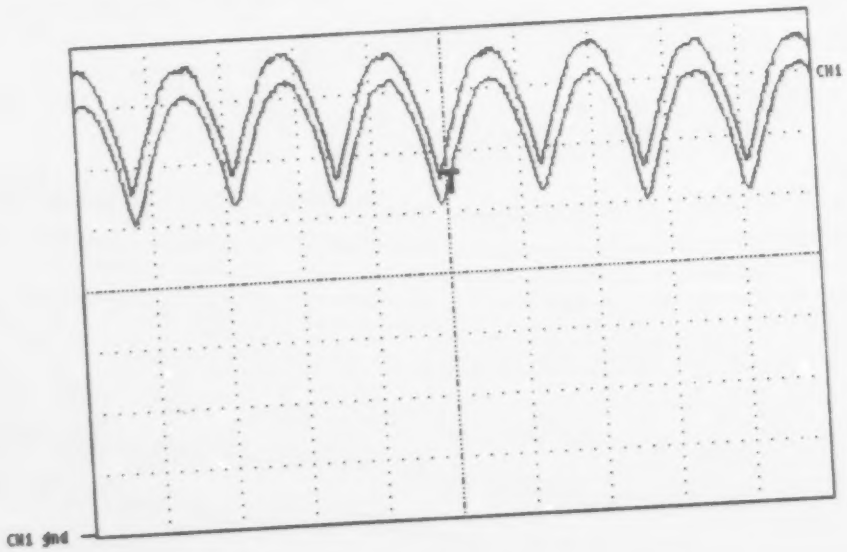
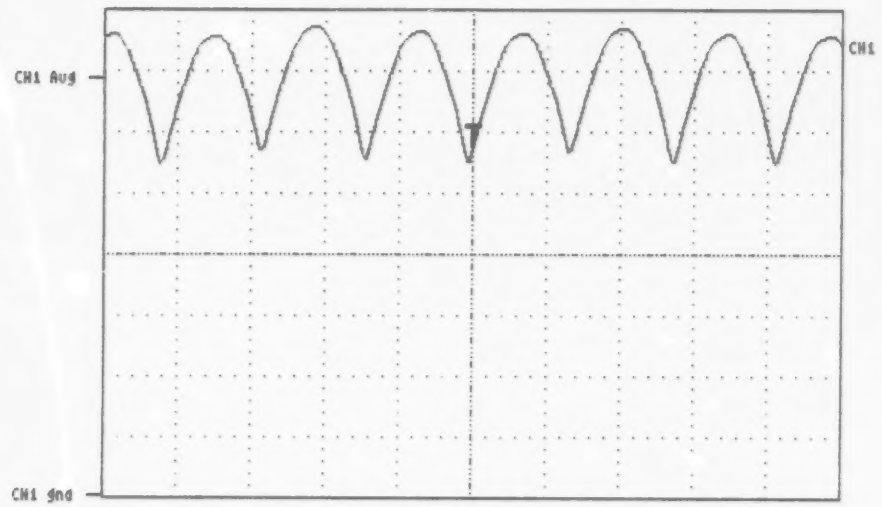


Figure C57 Light intensty @ 239 A. (18 in. up; 12 in. left)

CH1 5 mVΩ (Avg 34.3 mV, Max 38.7 mV, Min 27.3 mV, Rip 33.3%)
A 2 ms 50.30 V LINE Avg:256



CH1 5 mVΩ (Maxima(7): δMax 1.80 mV(5.3%), δAvg 1.66 mV(4.8%))
(Minima(7): δMax 1.80 mV(5.3%), δAvg 1.60 mV(4.7%))
A 2 ms 50.30 V LINE Env:256

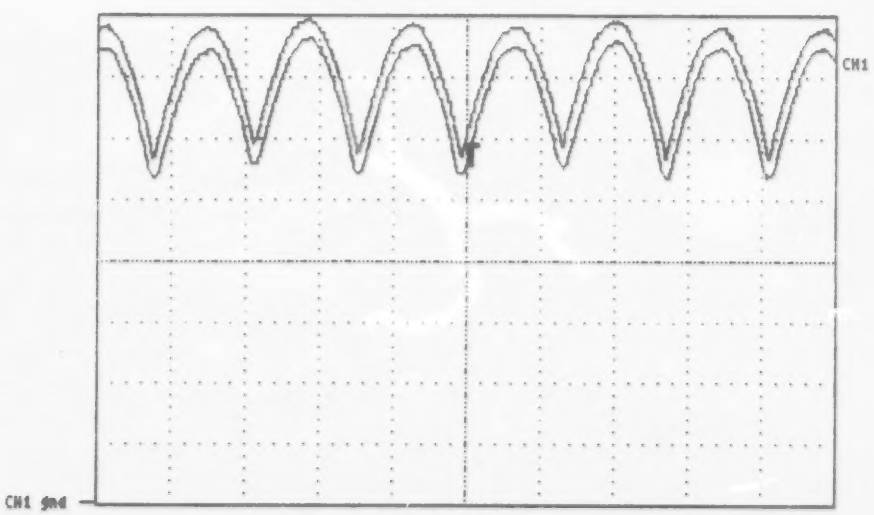
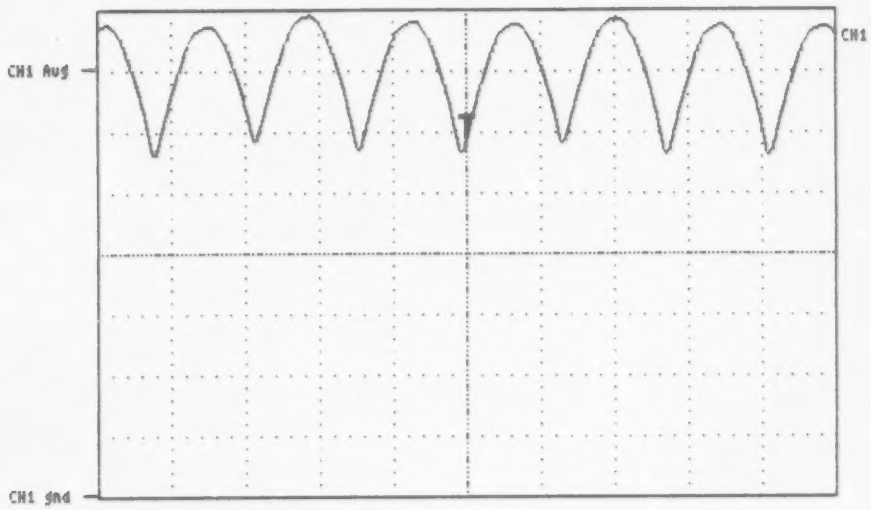


Figure C58 Light intensty @ 239 A. (18 in. up; 26 in. left)

CH1 5 mVΩ (Avg 35.0 mV, Max 39.4 mV, Min 28.1 mV, Rip 32.5%)
A 2 ms 50.30 V LINE Avg:256



CH1 5 mVΩ (Maxima(7): δMax 1.80 mV(5.1%), δAvg 1.69 mV(4.8%))
(Minima(7): δMax 2.00 mV(5.7%), δAvg 1.71 mV(4.9%))
A 2 ms 50.30 V LINE Env:256

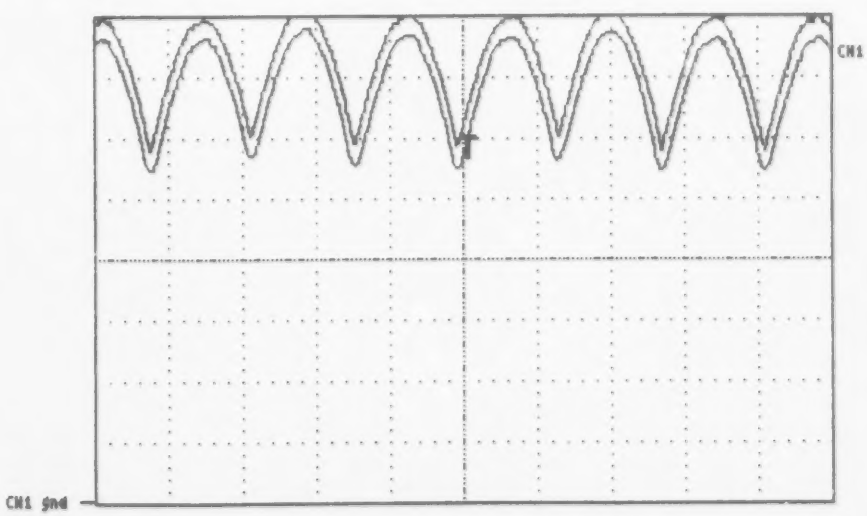
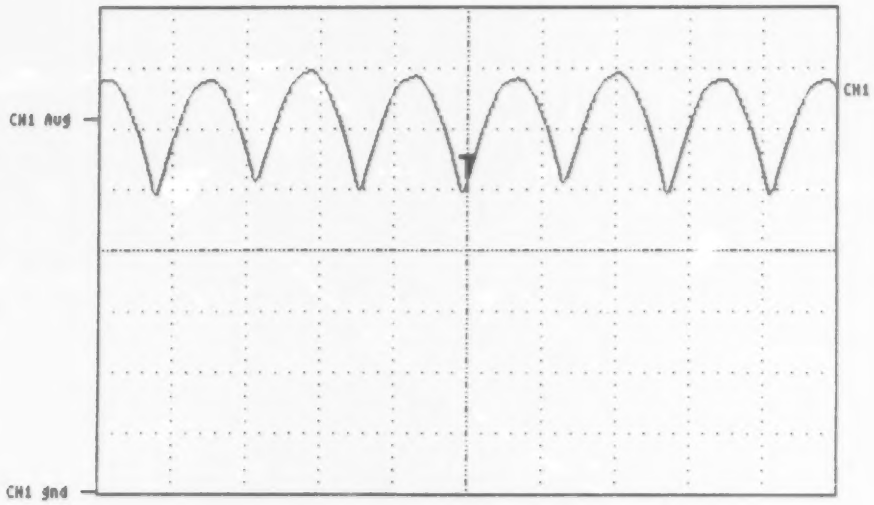


Figure C59 Light intensty @ 239 A. (18 in. up; 37 in. left)

CH1 5 mVΩ (Avg 30.7 mV, Max 34.6 mV, Min 24.4 mV, Rip 33.2%)
A 2 ms 50.30 V LINE Avg:256



CH1 5 mVΩ (Maxima(6): δMax 1.80 mV(5.9%), δAvg 1.60 mV(5.2%))
(Minima(7): δMax 2.00 mV(6.5%), δAvg 1.69 mV(5.5%))
A 2 ms 50.30 V LINE Env:256

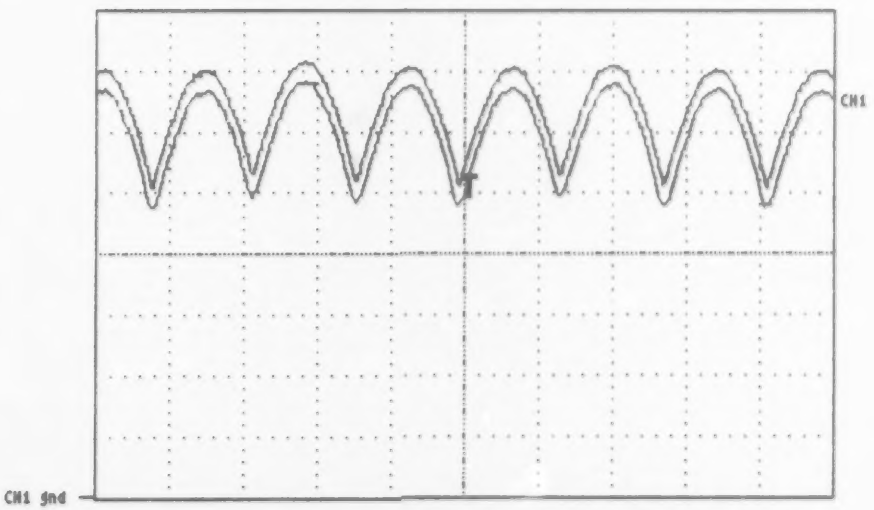
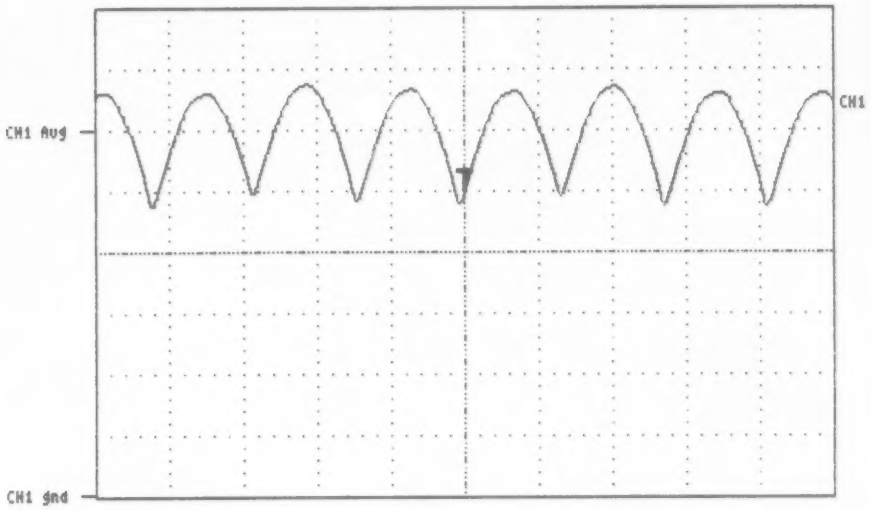


Figure C60 Light intensty @ 239 A. (18 in. up; 49 in. left)

CH1 5 mVΩ (Avg 29.8 mV, Max 33.7 mV, Min 23.7 mV, Rip 33.6%)
A 2 ms 50.30 V LINE Avg:256



CH1 5 mVΩ (Maxima(6): δMax 1.80 mV(6.8%), δAvg 1.60 mV(5.4%))
(Minima(7): δMax 1.60 mV(5.4%), δAvg 1.54 mV(5.2%))
A 2 ms 50.30 V LINE Env:256

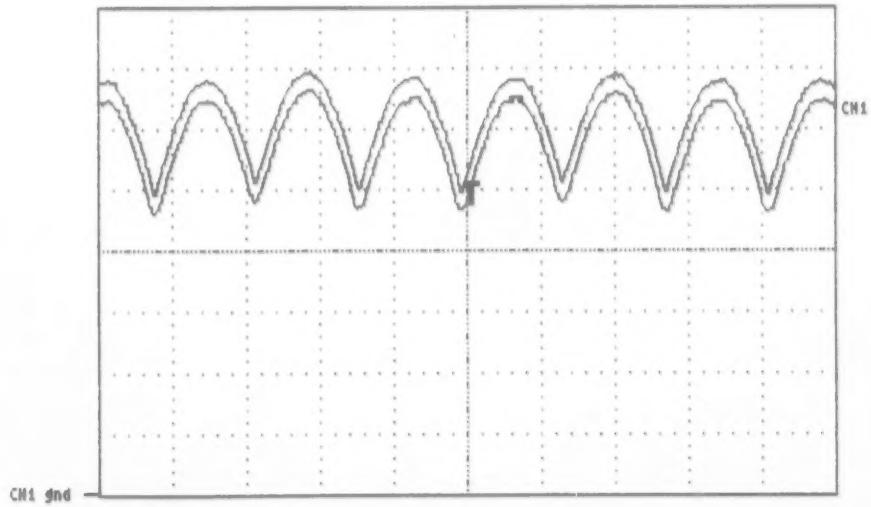
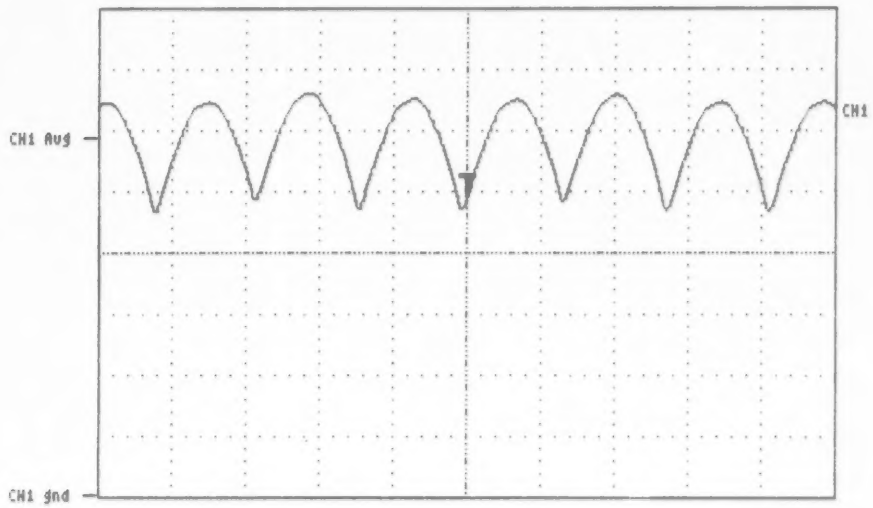


Figure C61 Light intensty @ 239 A. (18 in. up; 57 in. left)

CH1 5 mVΩ (Avg 29.2 mV, Max 32.9 mV, Min 23.3 mV, Rip 32.9%)
A 2 ms 50.30 V LINE Avg:256



CH1 5 mVΩ (Maxima(7): δMax 1.88 mV(6.2%), δAvg 1.66 mV(5.7%))
(Minima(7): δMax 1.88 mV(6.2%), δAvg 1.63 mV(5.6%))
A 2 ms 50.30 V LINE Env:256

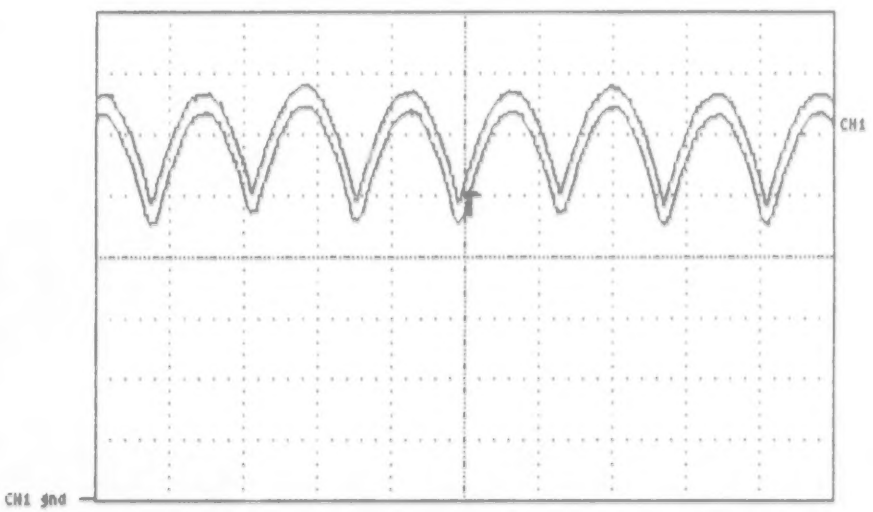
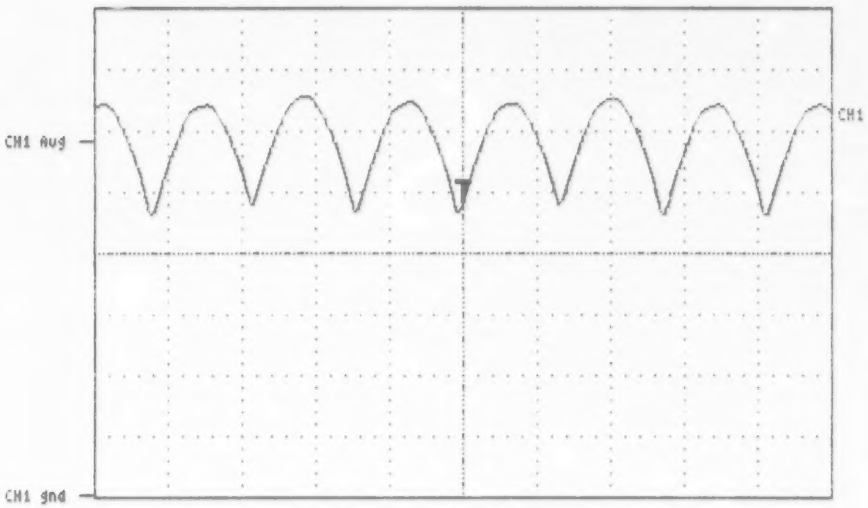


Figure C62 Light intensty @ 239 A. (12 in. up; 57 in. left)

CH1 5 mVΩ (Avg 29.8 mV, Max 32.6 mV, Min 23.1 mV, Rip 33.1%)
A 2 ms 50.30 V LINE Avg:256



CH1 5 mVΩ (Maxima(7): δMax 1.88 mV(6.2%), δAvg 1.69 mV(5.8%))
(Minima(7): δMax 1.88 mV(6.2%), δAvg 1.60 mV(5.5%))
A 2 ms 50.30 V LINE Env:256

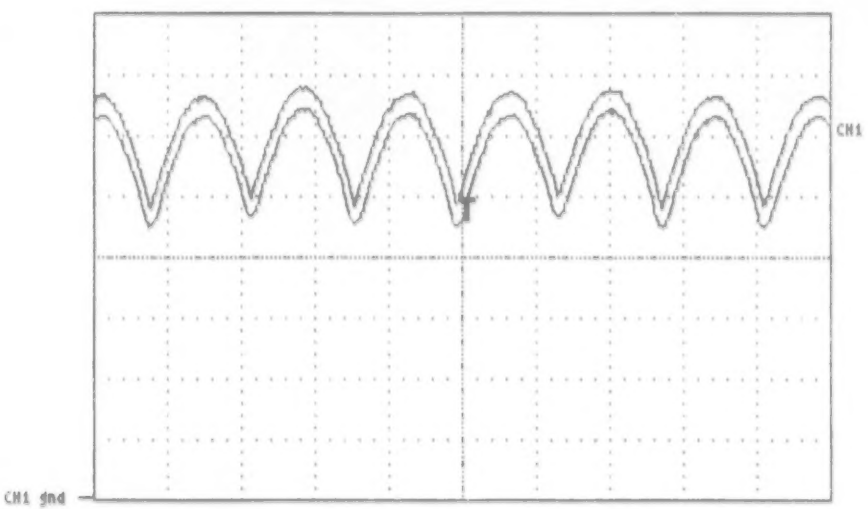
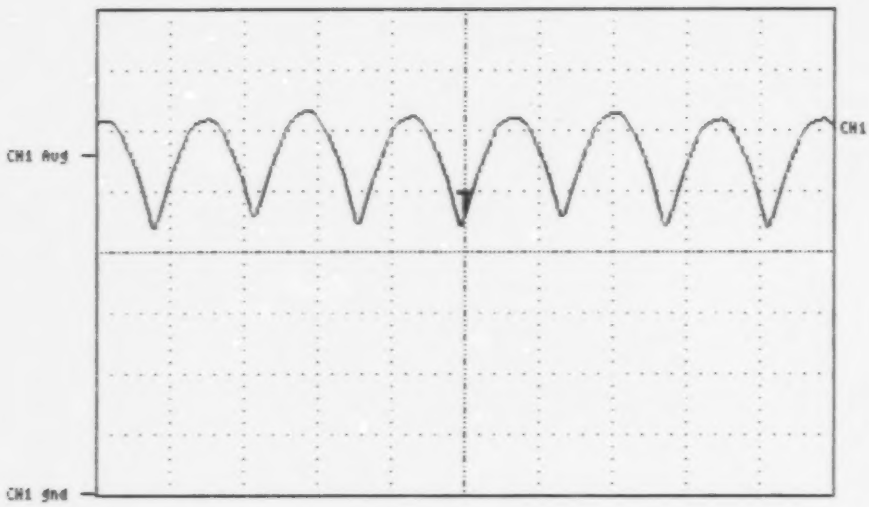


Figure C63 Light intensty @ 239 A. (6 in. up; 57 in. left)

CH1 5 mVΩ (Avg 27.8 mV, Max 31.4 mV, Min 21.9 mV, Rip 34.5%)
A 2 ms 50.30 V LINE Avg:256



CH1 5 mVΩ (Maxima(6): δMax 2.00 mV(7.2%), δAvg 1.67 mV(6.0%))
(Minima(7): δMax 1.88 mV(6.5%), δAvg 1.63 mV(5.9%))
A 2 ms 50.30 V LINE Env:256

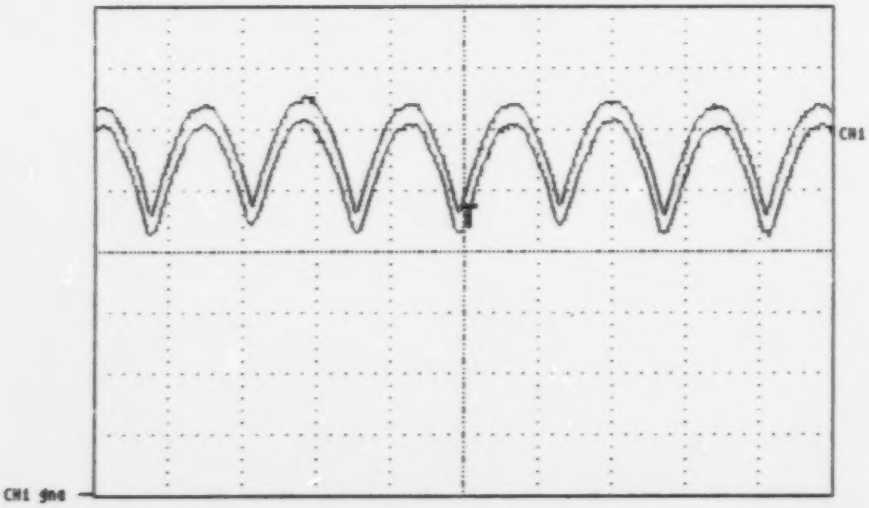
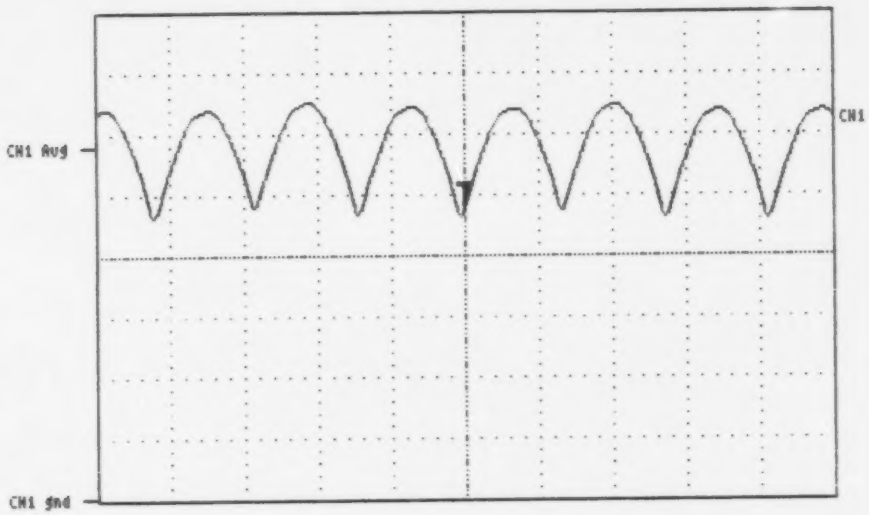


Figure C64 Light intensty @ 239 A. (24 in. up; 57 in. left)

CH1 5 mVΩ (Avg 28.8 mV, Max 32.5 mV, Min 22.9 mV, Rip 33.3%)
A 2 ms 50.30 V LINE Avg:256



CH1 5 mVΩ (Maxima(7): δMax 1.88 mV(6.2%), δAvg 1.60 mV(5.5%))
(Minima(7): δMax 1.88 mV(6.2%), δAvg 1.57 mV(5.4%))
A 2 ms 50.30 V LINE Env:256

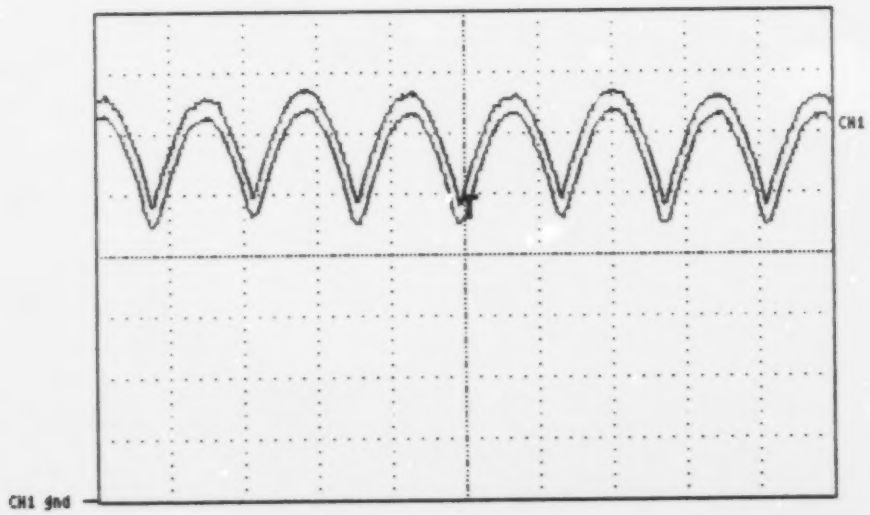
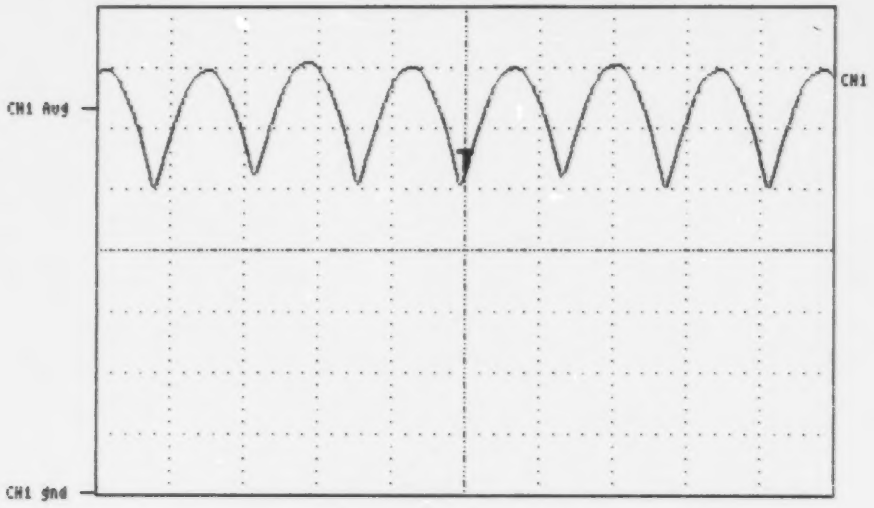


Figure C65 Light intensty @ 239 A. (18 in. up; 13 in. right)

CH1 5 mVΩ (Avg 31.4 mV, Max 35.3 mV, Min 25.8 mV, Rip 32.5%)
A 2 ms 50.30 V LINE Avg:256



CH1 5 mVΩ (Maxima(7): δMax 1.80 mV(5.7%), δAvg 1.66 mV(5.3%))
(Minima(7): δMax 1.80 mV(5.7%), δAvg 1.74 mV(5.5%))
A 2 ms 50.30 V LINE Env:256

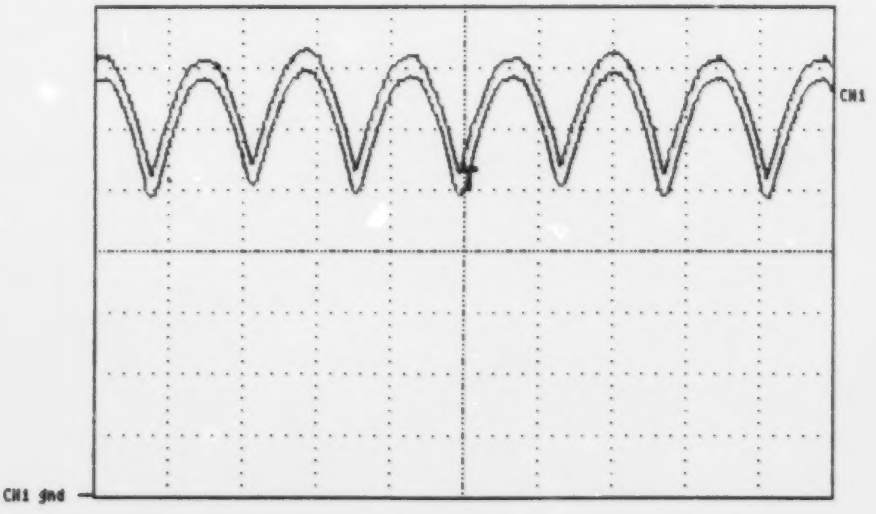
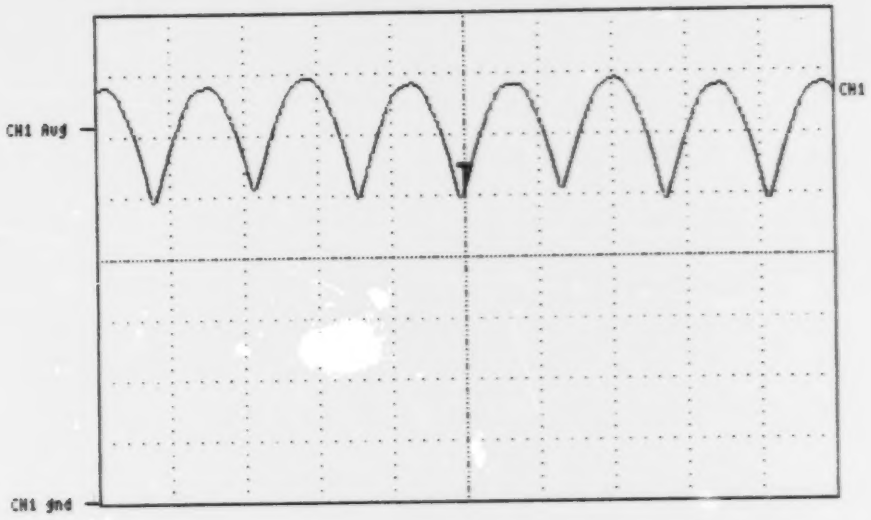


Figure C66 Light intensty @ 239 A. (18 in. up; 25 in. right)

CH1 5 mVΩ (Avg 30.7 mV, Max 34.4 mV, Min 24.4 mV, Rip 32.6%)
A 2 ms 50.30 V LINE Avg:256



CH1 5 mVΩ (Maxima(7): δMax 1.60 mV(5.2%), δAvg 1.51 mV(4.9%))
(Minima(7): δMax 2.00 mV(6.5%), δAvg 1.80 mV(5.9%))
A 2 ms 50.30 V LINE Env:256

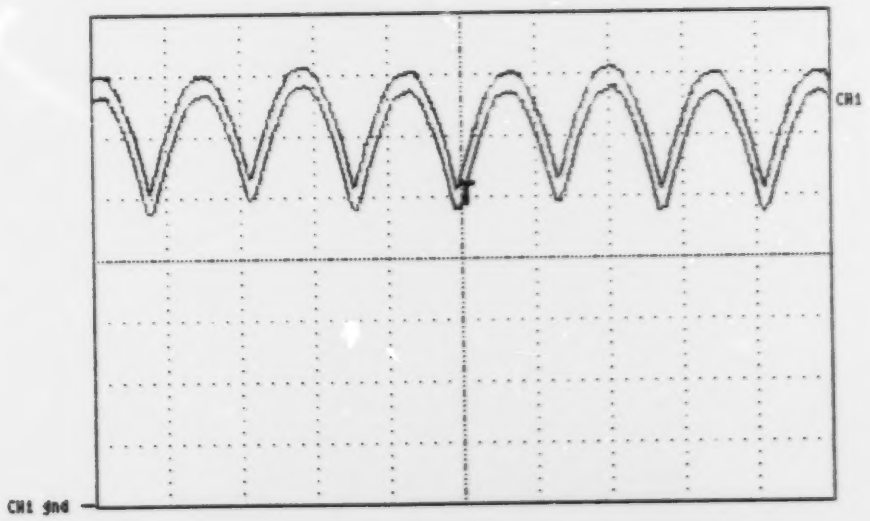
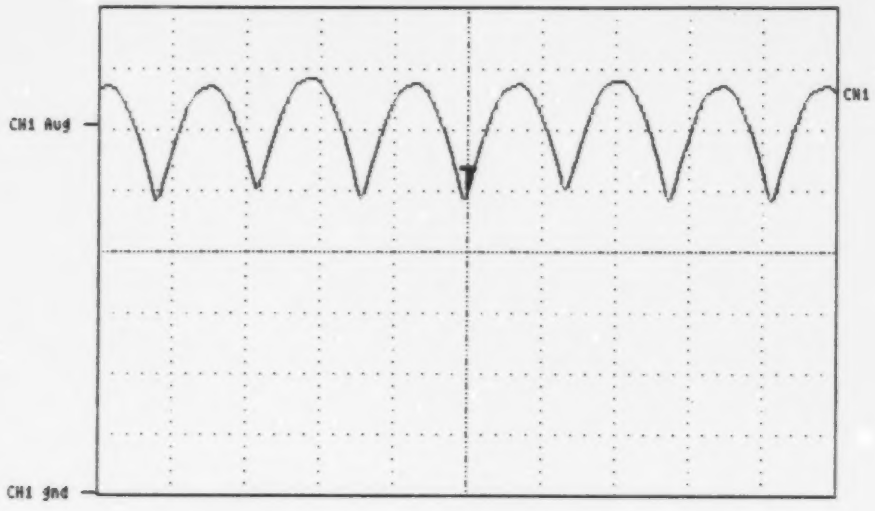


Figure C67 Light intensty @ 239 A. (18 in. up; 33 in. right)

CH1 5 mVΩ (Avg 30.3 mV, Max 34.3 mV, Min 24.0 mV, Rip 33.6%)
A 2 ms 50.30 V LINE Avg:256



CH1 5 mVΩ (Maxima(7): δMax 1.60 mV(5.3%), δAvg 1.57 mV(5.2%))
(Minima(7): δMax 1.80 mV(5.9%), δAvg 1.66 mV(5.5%))
A 2 ms 50.30 V LINE Env:256

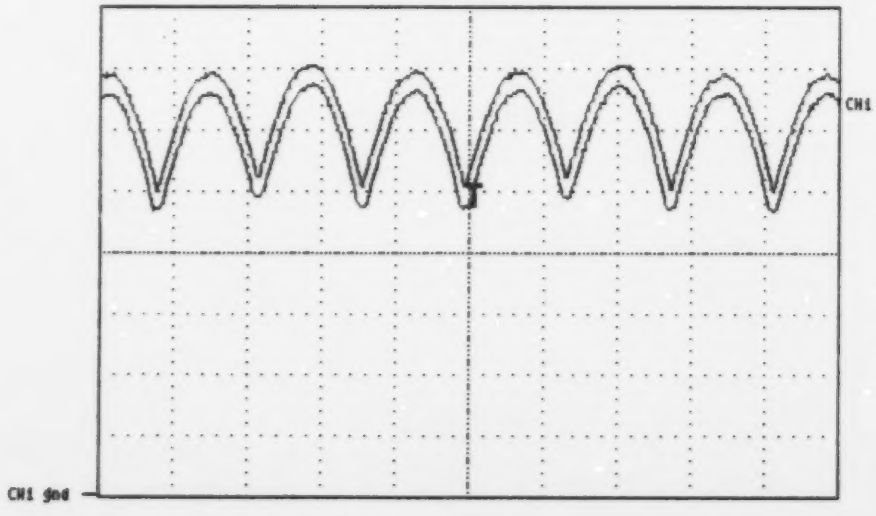
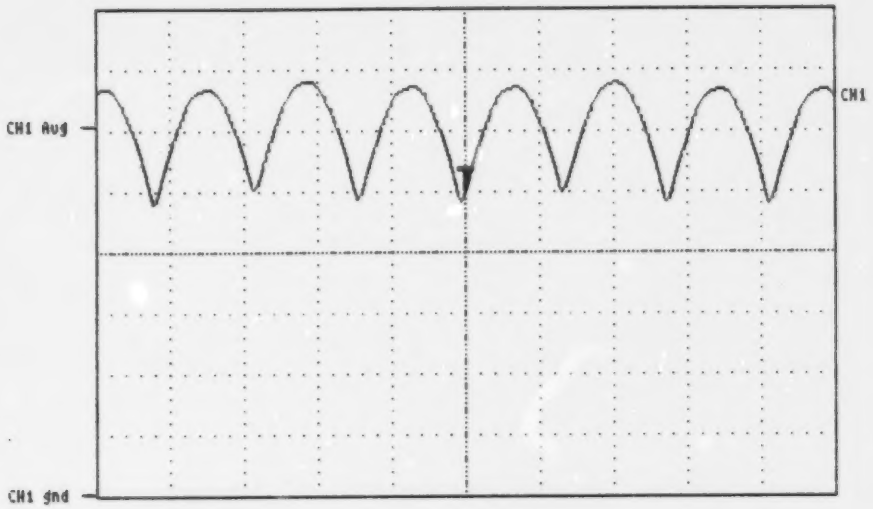


Figure C68 Light intensty @ 239 A. (18 in. up; 46 in. right)

CH1 5 mVΩ (Avg 30.2 mV, Max 33.8 mV, Min 23.8 mV, Rip 33.1%)
A 2 ms 50.30 V LINE Avg:256



CH1 5 mVΩ (Maxima(7): δMax 1.60 mV(5.3%), δAvg 1.54 mV(5.1%))
(Minima(7): δMax 1.80 mV(6.0%), δAvg 1.63 mV(5.4%))
A 2 ms 50.30 V LINE Env:256

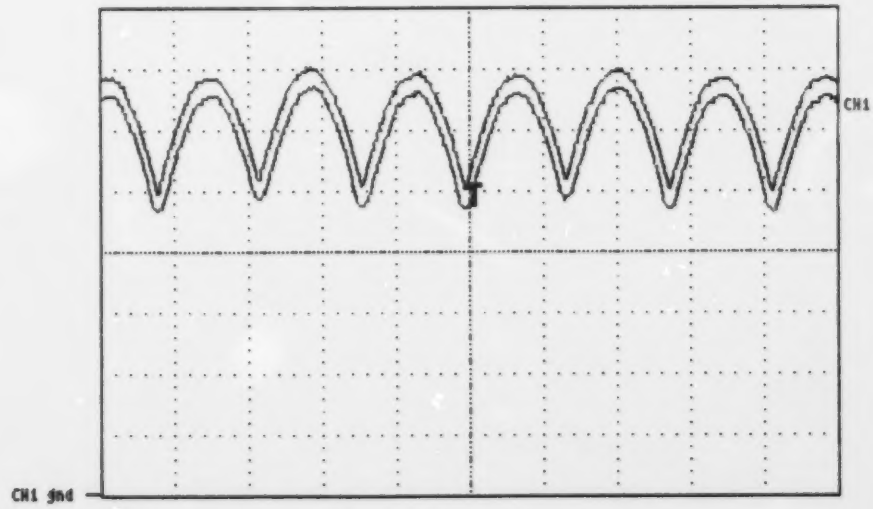
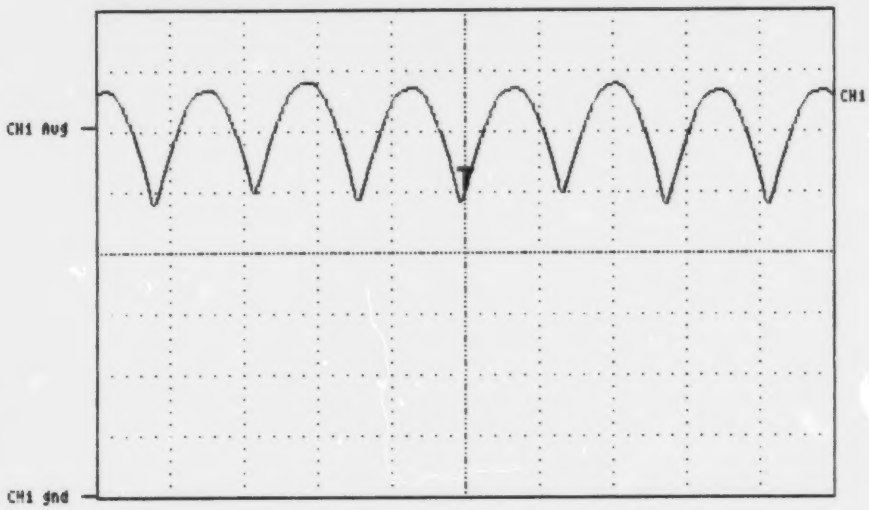


Figure C69 Light intensty @ 239 A. (12 in. up; 46 in. right)

CH1 5 mVΩ (Avg 30.2 mV, Max 34.0 mV, Min 23.8 mV, Rip 33.8%)
A 2 ms 50.30 V LINE Avg:256



CH1 5 mVΩ (Maxima(7): δMax 1.80 mV(6.0%), δAvg 1.57 mV(5.2%))
(Minima(7): δMax 2.00 mV(6.6%), δAvg 1.69 mV(5.6%))
A 2 ms 50.30 V LINE Env:256

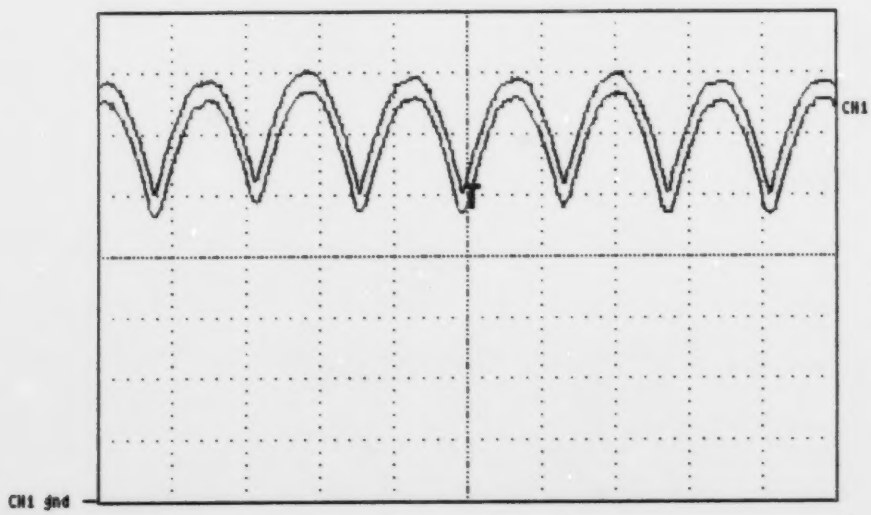
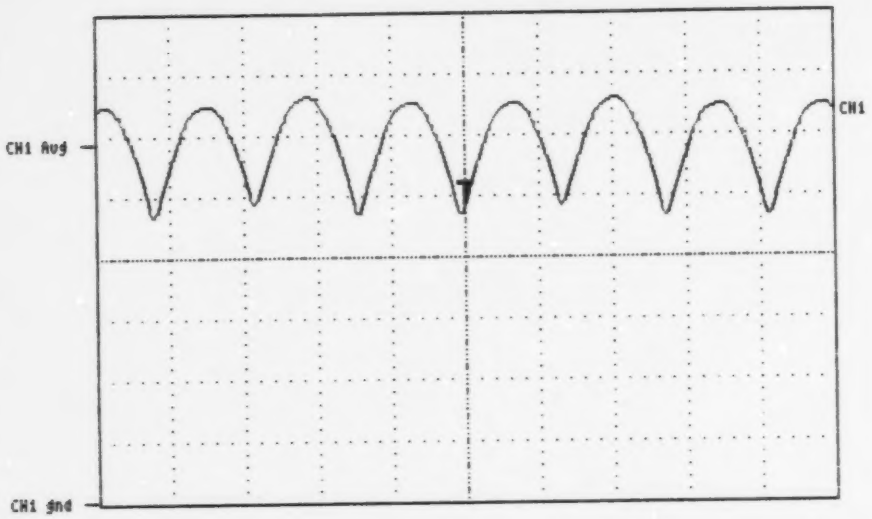


Figure C70 Light intensty @ 239 A. (6 in. up; 46 in. right)

CH1 5 mVΩ (Avg 29.3 mV, Max 33.1 mV, Min 23.3 mV, Rip 33.5%)
A 2 ms 50.30 V LINE Avg:256



CH1 5 mVΩ (Maxima(6): δMax 1.80 mV(6.1%), δAvg 1.67 mV(5.7%))
(Minima(7): δMax 1.80 mV(6.1%), δAvg 1.60 mV(5.5%))
A 2 ms 50.30 V LINE Env:256

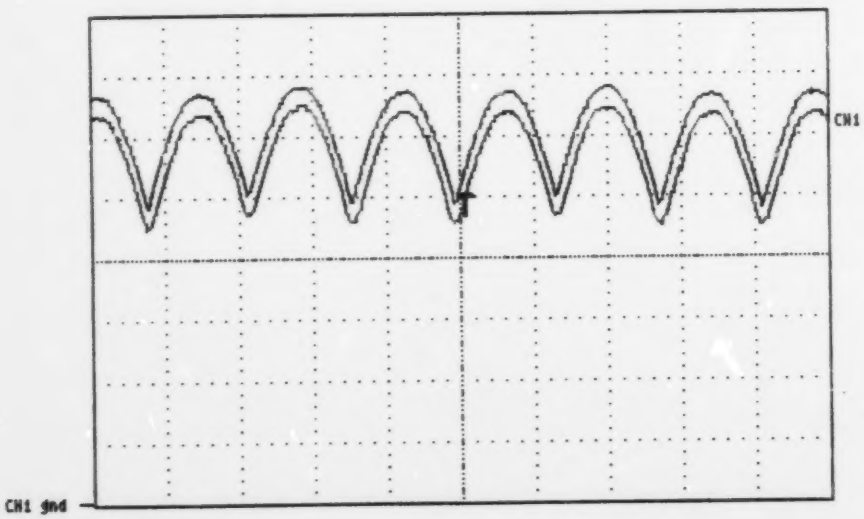
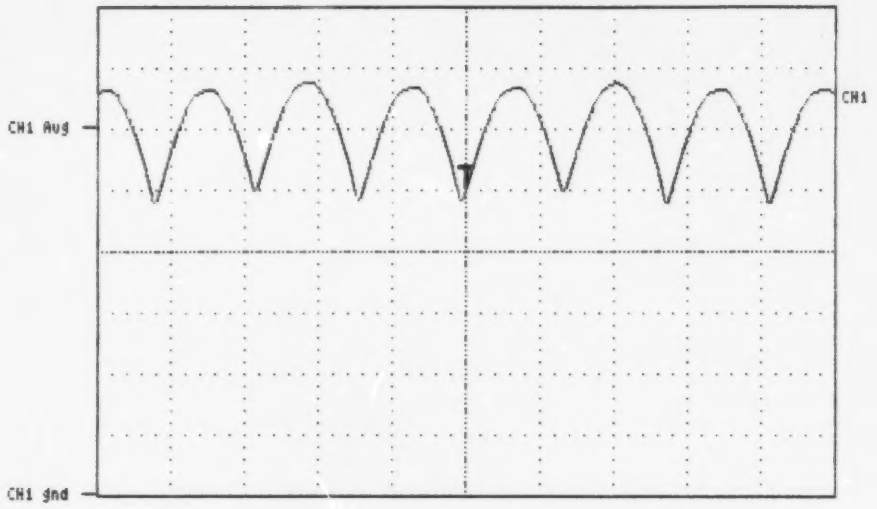


Figure C71 Light intensty @ 239 A. (24 in. up; 46 in. right)

CH1 5 mVΩ (Avg 30.0 mV, Max 33.7 mV, Min 23.8 mV, Rip 32.6%)
A 2 ms 50.30 V LINE Avg:256



CH1 5 mVΩ (Maxima(6): δMax 1.60 mV(5.3%), δAvg 1.43 mV(4.8%))
(Minima(7): δMax 1.80 mV(6.0%), δAvg 1.60 mV(5.3%))
A 2 ms 50.30 V LINE Env:256

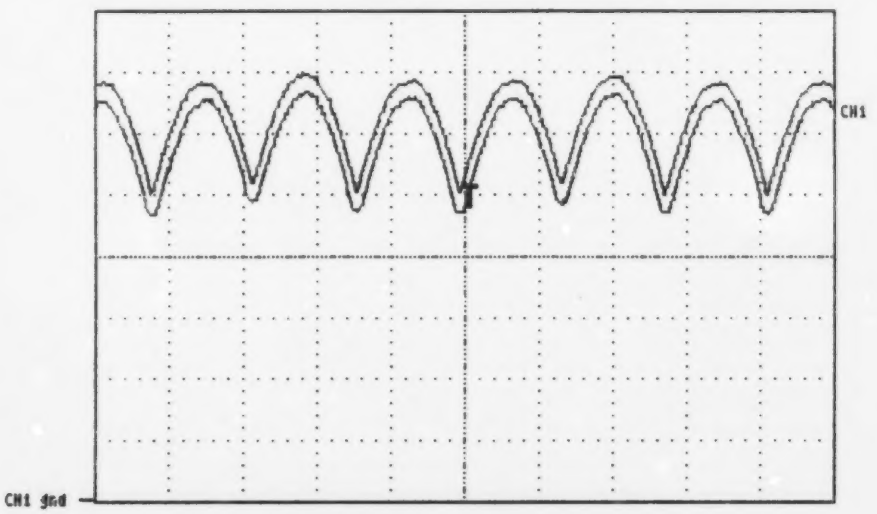
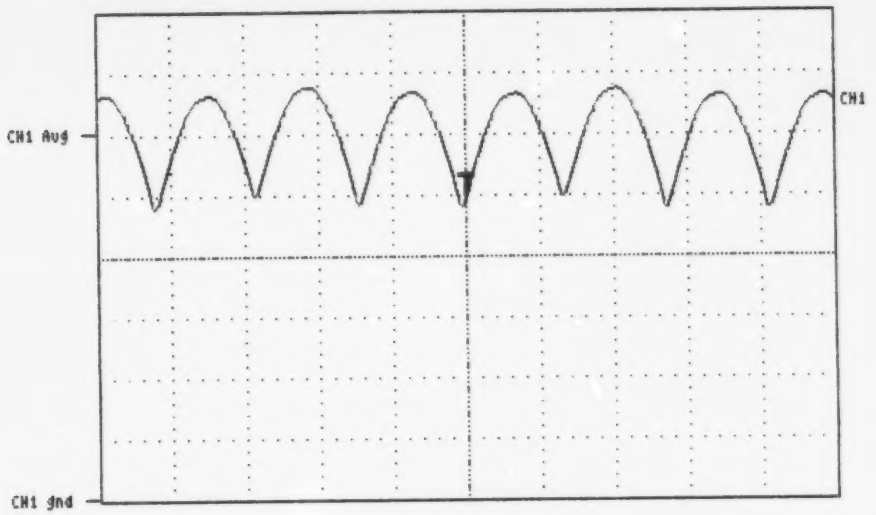
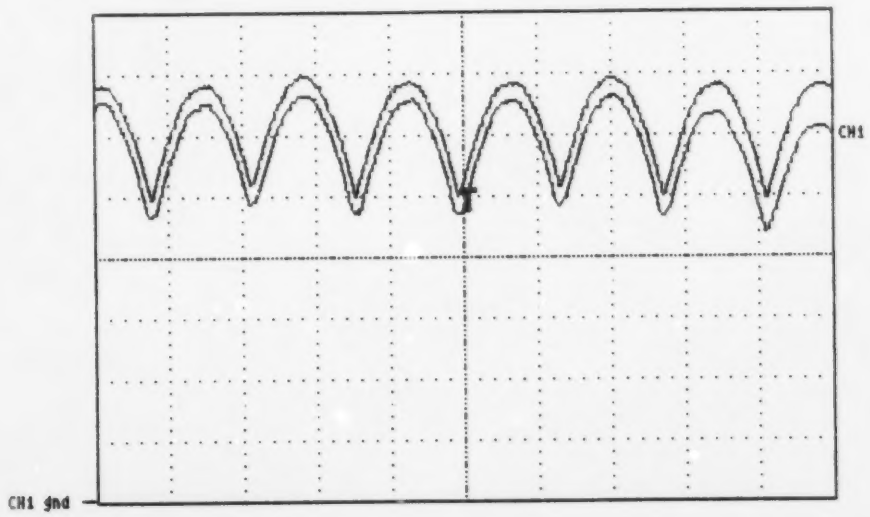


Figure C72 Light intensty @ 239 A. (24 in. up; 46 in. right)

CH1 5 mVΩ (Avg 30.0 mV, Max 33.7 mV, Min 23.8 mV, Rip 32.7%)
A 2 ms 50.30 V LINE Avg:256



CH1 5 mVΩ (Maxima(6): δMax 2.40 mV(8.8%), δAvg 1.67 mV(5.6%))
(Minima(7): δMax 2.80 mV(9.3%), δAvg 1.69 mV(5.6%))
A 2 ms 50.30 V LINE Env:256



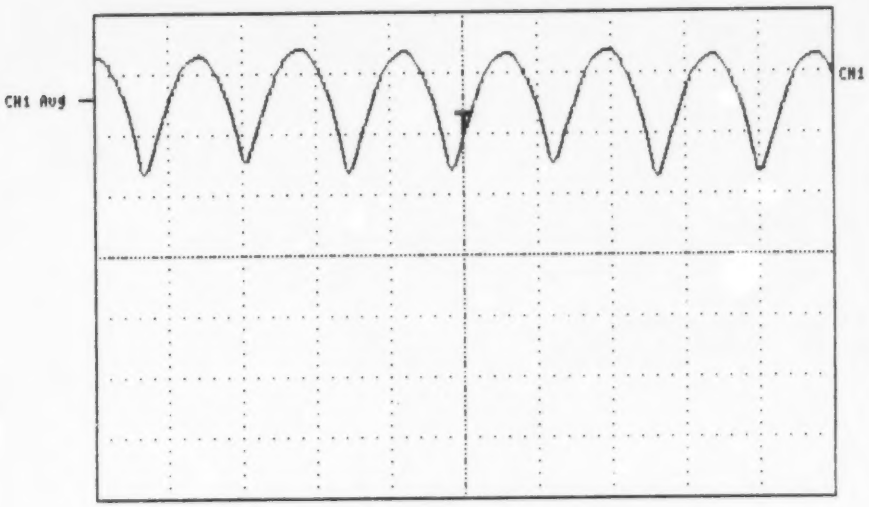
APPENDIX C

Table C5. Summary of data for the arc intensity at 300 Amps.

Figure (#)	Position to center right (in.)	up (in.)	Ripple (%)	Maxima max. (%)	Maxima avg. (%)	Minima max. (%)	Minima avg. (%)
C73	0	6	24.3	4.1	3.9	4.1	3.8
C74	0	18	24.0	3.6	3.3	3.6	3.3
C75	-12	18	24.6	3.7	3.5	3.7	3.5
C76	-26	18	24.8	4.2	3.6	4.2	3.8
C77	-37	18	24.3	4.3	3.7	3.8	3.4
C78	-49	18	24.3	5.0	4.6	5.0	4.3
C79	-57	18	23.8	4.6	4.0	4.6	3.8
C80	-57	12	24.5	6.5	4.0	6.5	4.1
C81	-57	6	24.6	8.7	7.3	8.7	7.3
C82	-57	24	24.6	4.2	4.1	4.2	4.0
C83	13	18	23.7	4.2	3.6	3.7	3.7
C84	25	18	23.7	9.9	6.6	13.3	7.2
C85	33	18	24.0	4.4	3.9	3.9	3.7
C86	46	18	23.9	4.4	3.7	4.4	3.8
C87	46	12	24.1	17.4	6.4	13.0	5.4
C88	46	6	24.6	4.5	4.0	4.0	3.8
C89	46	24	24.3	5.0	4.4	6.0	4.8
C90	46	24	24.3	4.0	3.9	4.0	3.8
Average			24.24	5.59	4.36	5.59	4.31
Std. Dev.			0.33	3.29	1.13	2.94	1.15

Figure C73 Light intensty @ 300 A. (6 in. up; center)

CH1 5 mVΩ (Avg 43.7 mV, Max 47.6 mV, Min 37.0 mV, Rip 24.3%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(7): δMax 1.80 mV(4.1%), δAvg 1.71 mV(3.9%))
(Minima(7): δMax 1.80 mV(4.1%), δAvg 1.66 mV(3.8%))
A 2 ms 50.30 V LINE Env:256

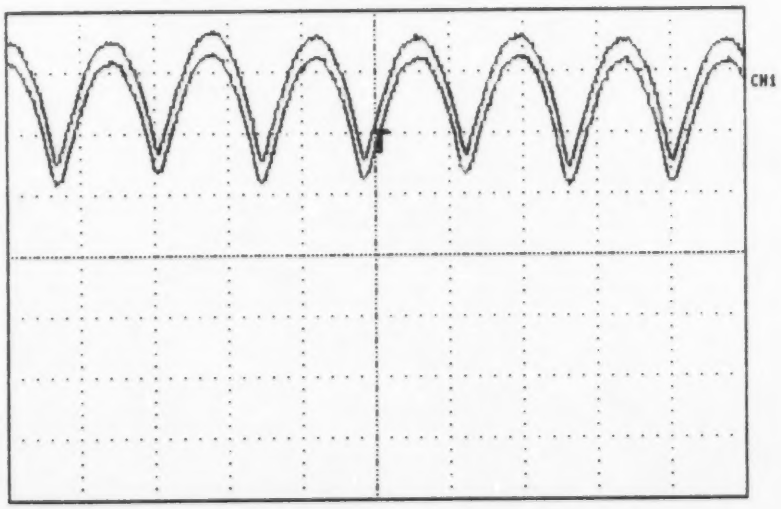
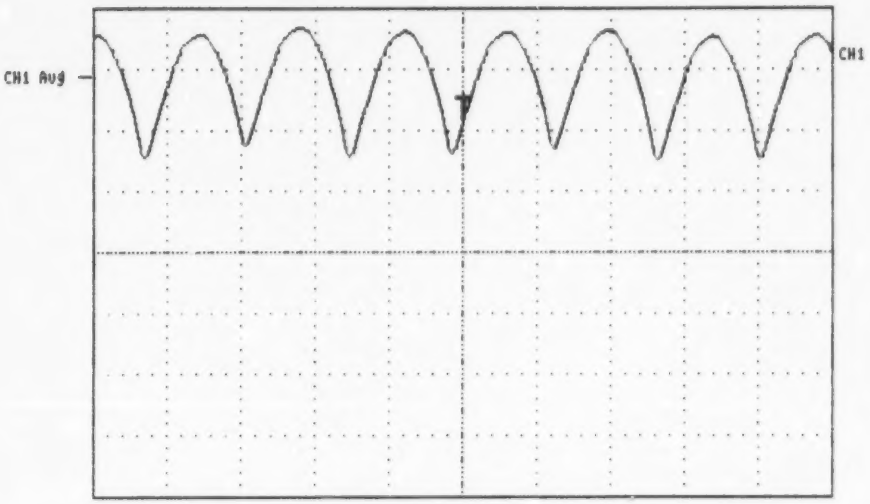


Figure C74 Light intensty @ 300 A. (18 in. up; center)

CH1 5 mVΩ (Avg 44.9 mV, Max 49.0 mV, Min 38.2 mV, Rip 24.0%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(6): δMax 1.60 mV(3.6%), δAvg 1.50 mV(3.3%))
(Minima(7): δMax 1.60 mV(3.6%), δAvg 1.49 mV(3.3%))
A 2 ms 50.30 V LINE Env:256

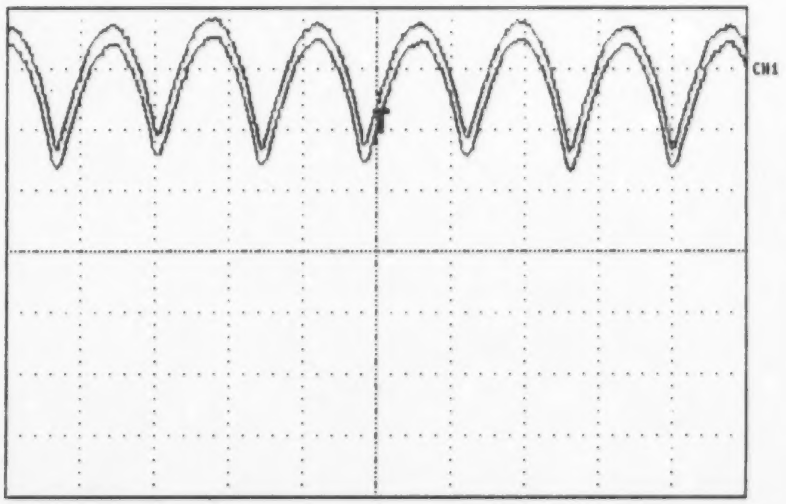
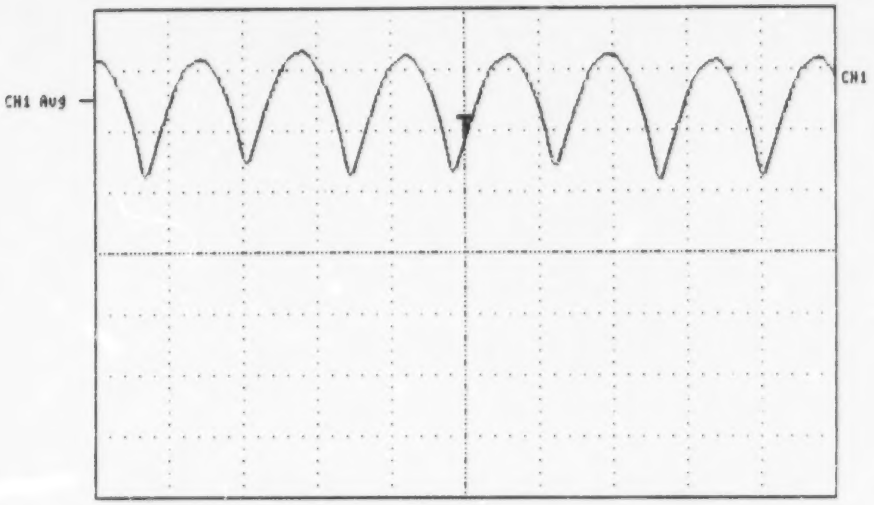


Figure C75 Light intensty @ 300 A. (18 in. up; 12 in. left)

CH1 5 mVΩ (Avg 43.2 mV, Max 47.2 mV, Min 36.6 mV, Rip 24.6%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(7): δMax 1.60 mV(3.7%), δAvg 1.51 mV(3.5%))
(Minima(7): δMax 1.60 mV(3.7%), δAvg 1.51 mV(3.5%))
A 2 ms 50.30 V LINE Env:256

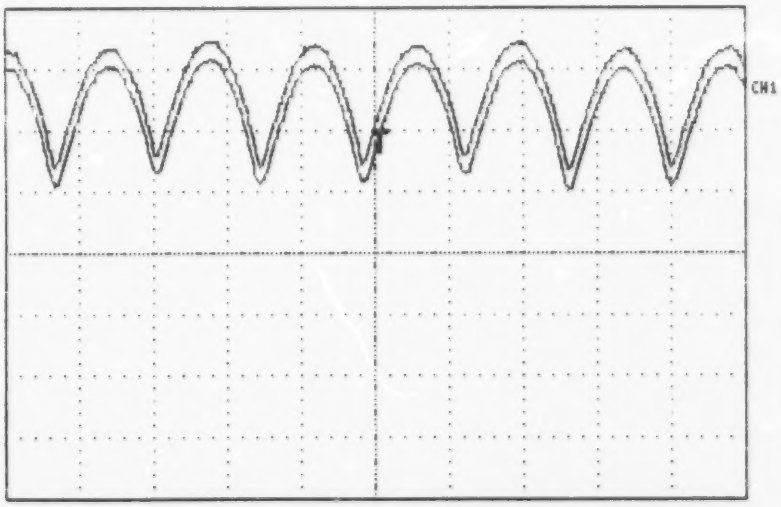
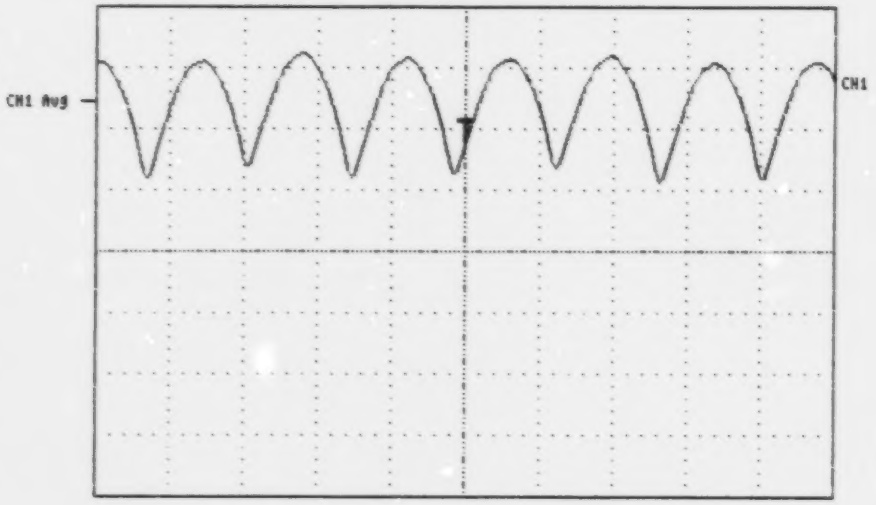


Figure C76 Light intensty @ 300 A. (18 in. up; 26 in. left)

CH1 5 mVΩ (Avg 42.8 mV, Max 46.8 mV, Min 36.2 mV, Rip 24.8%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(7): δMax 1.80 mV(4.2%), δAvg 1.54 mV(3.6%))
(Minima(7): δMax 1.80 mV(4.2%), δAvg 1.63 mV(3.8%))
A 2 ms 50.30 V LINE Env:256

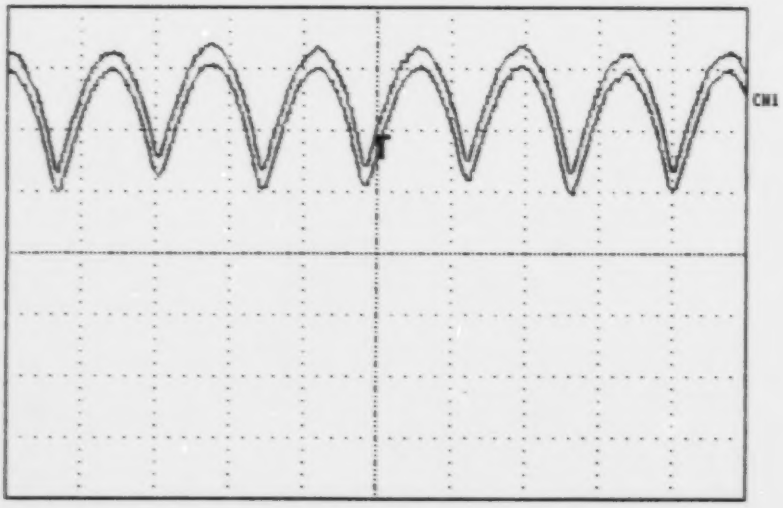
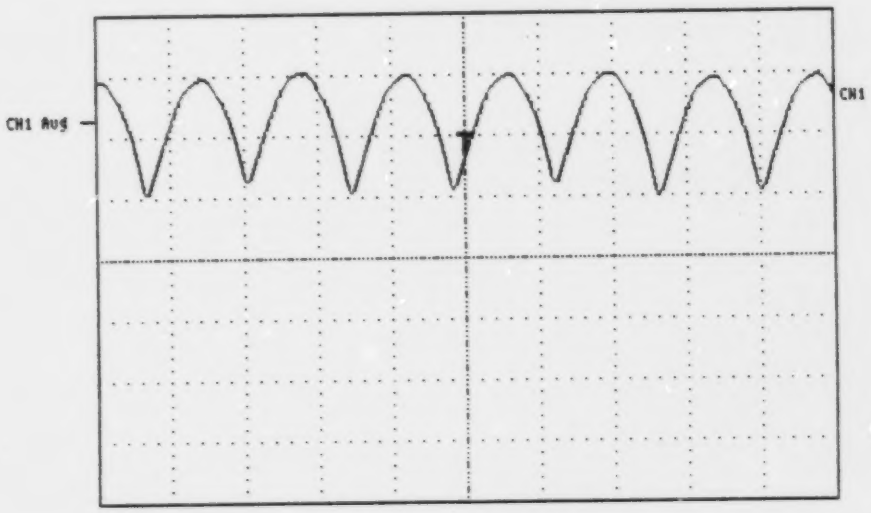


Figure C77 Light intensty @ 300 A. (18 in. up; 37 in. left)

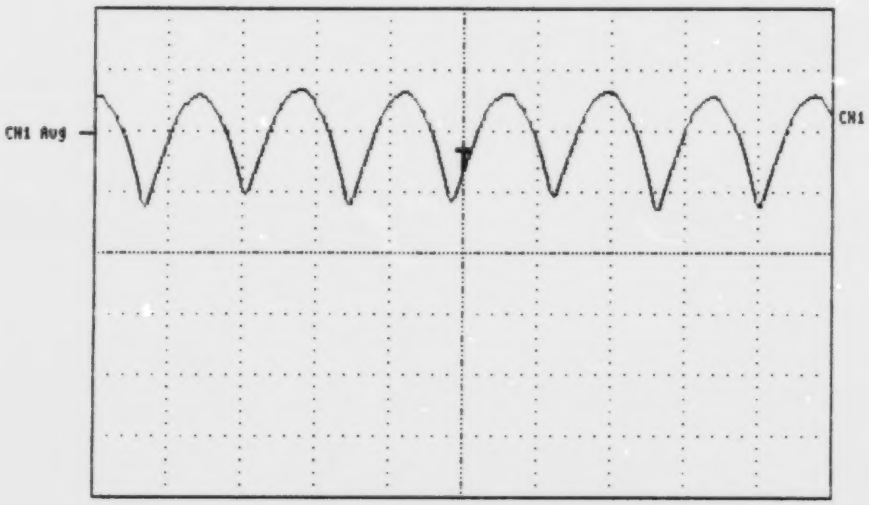
CH1 5 mV Ω (Avg 42.1 mV, Max 45.8 mV, Min 35.6 mV, Rip 24.3%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mV Ω (Maxima(7): δMax 1.80 mV(4.3%), δAvg 1.54 mV(3.7%))
(Minima(7): δMax 1.60 mV(3.8%), δAvg 1.43 mV(3.4%))
A 2 ms 50.30 V LINE Env:256

Figure C78 Light intensty @ 300 A. (18 in. up; 49 in. left)

CH1 5 mVΩ (Avg 40.4 mV, Max 44.0 mV, Min 34.2 mV, Rip 24.3%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(7): δMax 2.00 mV(5.0%), δAvg 1.86 mV(4.6%))
(Minima(7): δMax 2.00 mV(5.0%), δAvg 1.74 mV(4.3%))
A 2 ms 50.30 V LINE Env:256

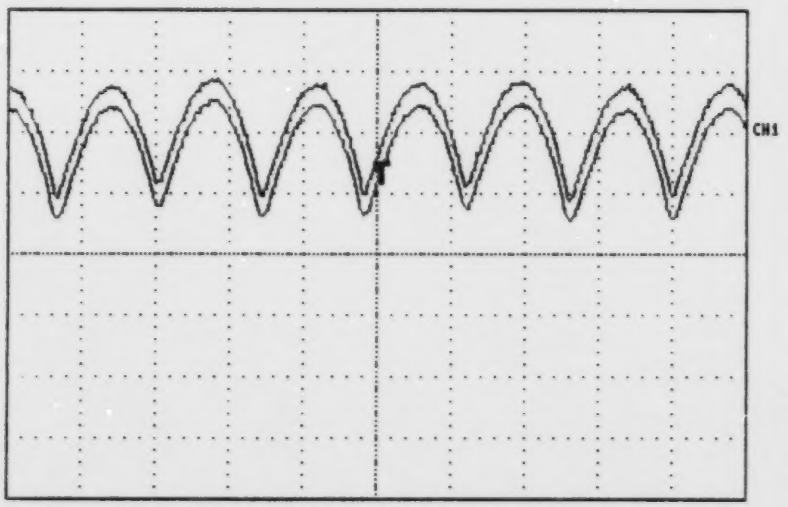
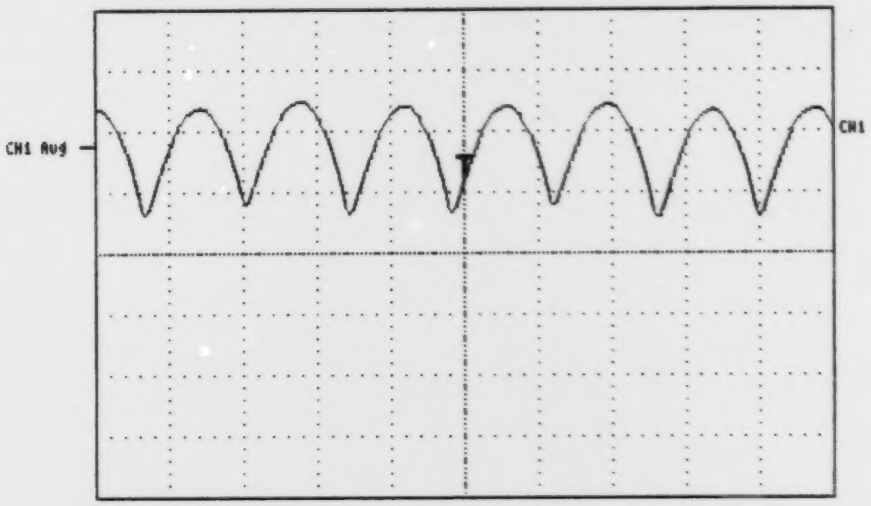


Figure C79 Light intensty @ 300 A. (18 in. up; 57 in. left)

CH1 5 mVΩ (Avg 39.4 mV, Max 43.0 mV, Min 33.6 mV, Rip 23.8%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(7): δMax 1.80 mV(4.6%), δAvg 1.57 mV(4.8%))
(Minima(7): δMax 1.80 mV(4.6%), δAvg 1.49 mV(3.8%))
A 2 ms 50.30 V LINE Env:256

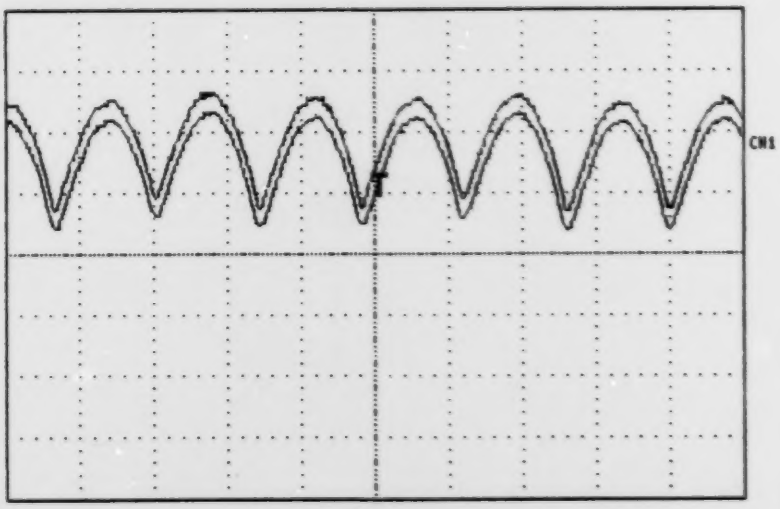
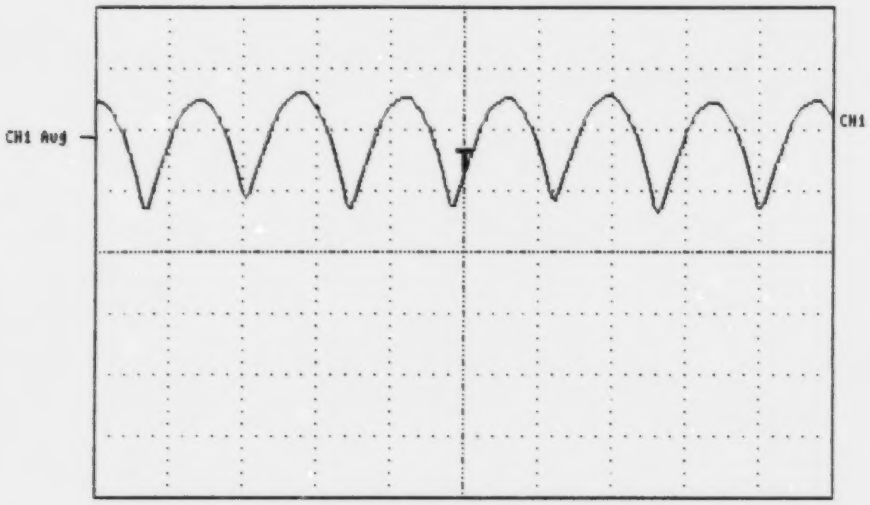


Figure C88 Light intensty @ 300 A. (12 in. up; 57 in. left)

CH1 5 mVΩ (Avg 39.9 mV, Max 43.6 mV, Min 33.8 mV, Rip 24.5%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(7): δMax 1.80 mV(4.5%), δAvg 1.60 mV(4.8%))
(Minima(7): δMax 2.60 mV(6.5%), δAvg 1.63 mV(4.1%))
A 2 ms 50.30 V LINE Env:256

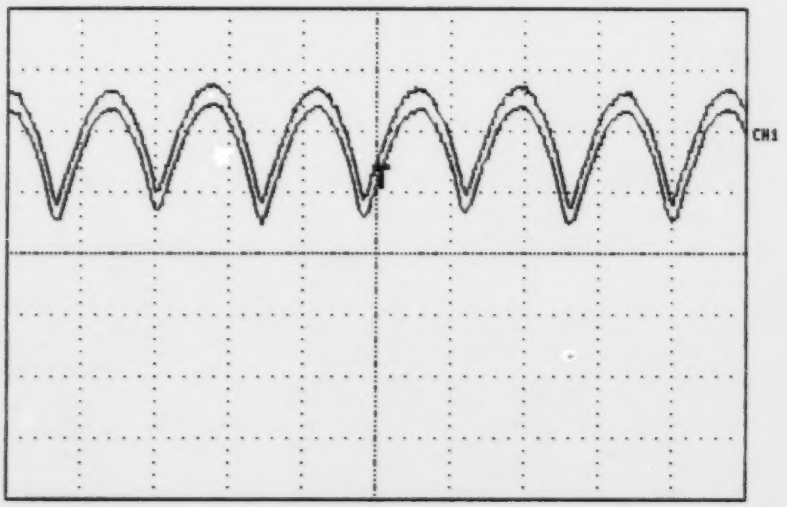
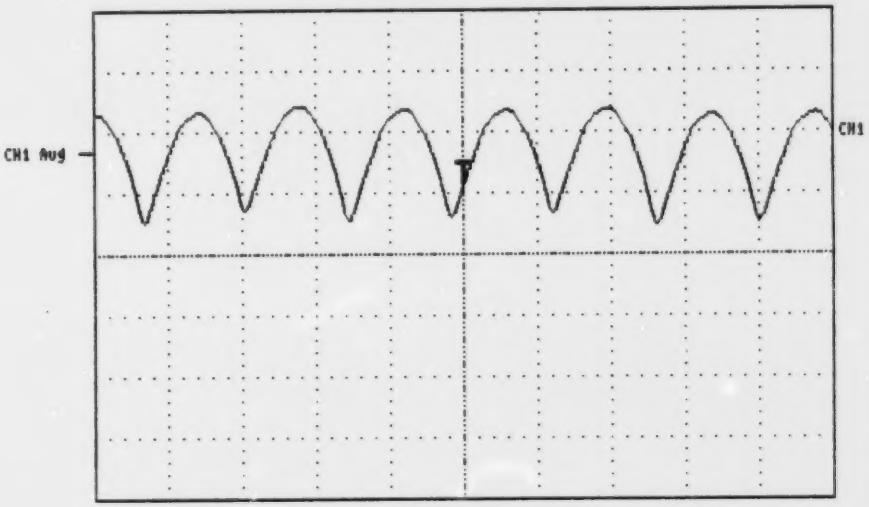


Figure C81 Light intensty @ 300 A. (6 in. up; 57 in. left)

CH1 5 mVΩ (Avg 39.1 mV, Max 42.6 mV, Min 33.0 mV, Rip 24.6%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(6): δMax 3.40 mV(8.7%), δAvg 2.83 mV(7.3%))
(Minima(7): δMax 3.40 mV(8.7%), δAvg 2.86 mV(7.3%))
A 2 ms 50.30 V LINE Env:256

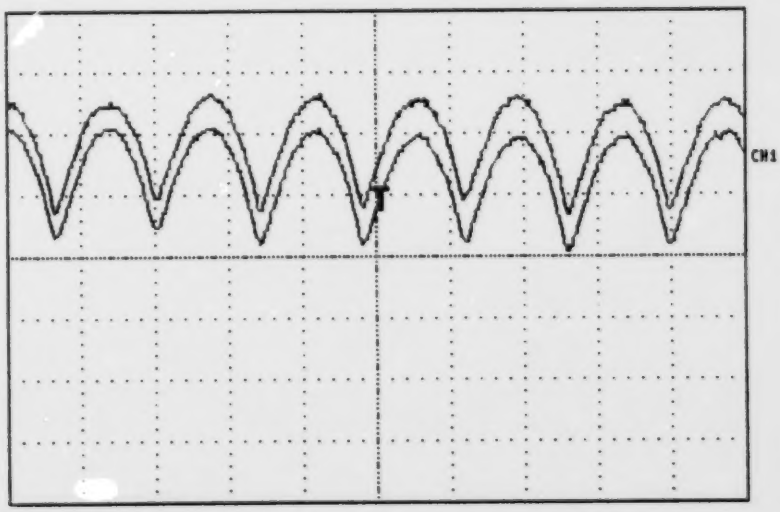
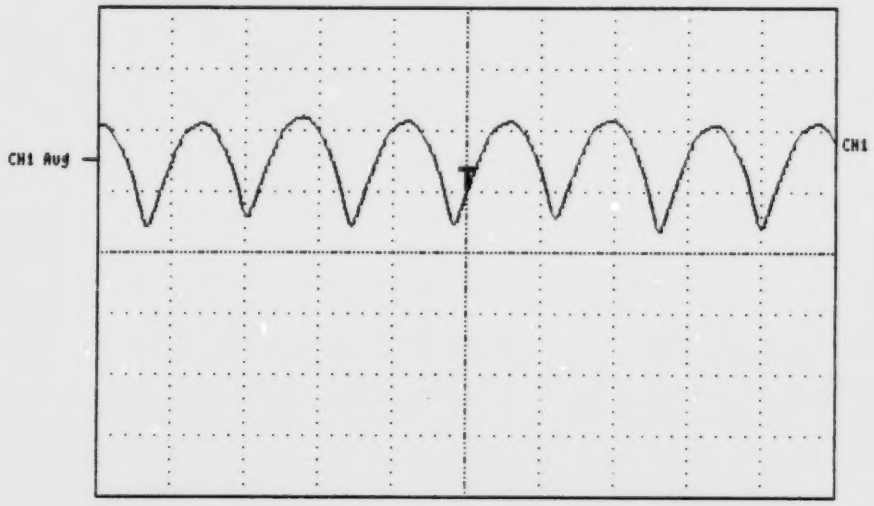


Figure C82 Light intensty @ 300 A. (24 in. up; 57 in. left)

CH1 5 mVΩ (Avg 38.3 mV, Max 41.8 mV, Min 32.4 mV, Rip 24.6%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(7): δMax 1.60 mV(4.2%), δAvg 1.57 mV(4.1%))
(Minima(7): δMax 1.60 mV(4.2%), δAvg 1.51 mV(4.0%))
A 2 ms 50.30 V LINE Env:256

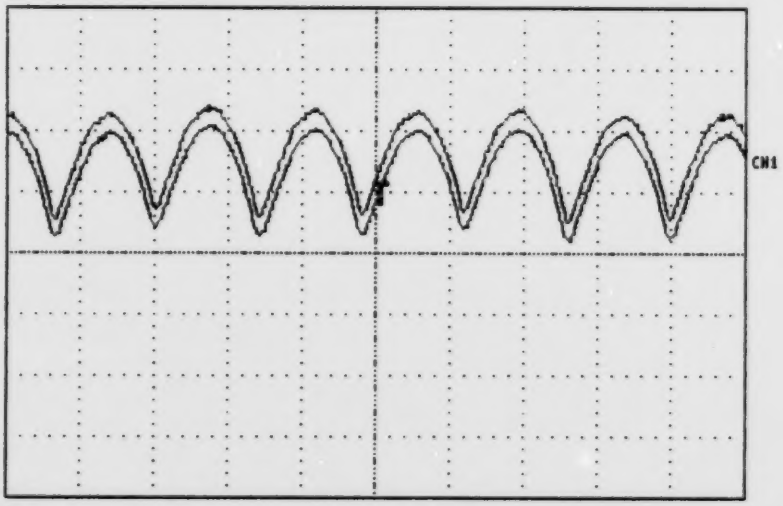
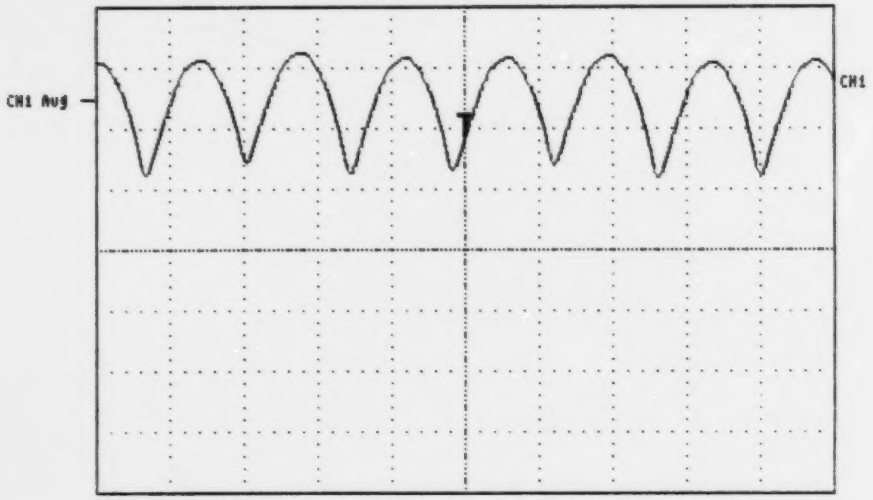


Figure C83 Light intensty @ 300 A. (18 in. up; 13 in. right)

CH1 5 mVΩ (Avg 43.0 mV, Max 46.8 mV, Min 36.6 mV, Rip 23.7%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(6): δMax 1.80 mV(4.2%), δAvg 1.53 mV(3.6%))
(Minima(7): δMax 1.60 mV(3.7%), δAvg 1.57 mV(3.7%))
A 2 ms 50.30 V LINE Env:256

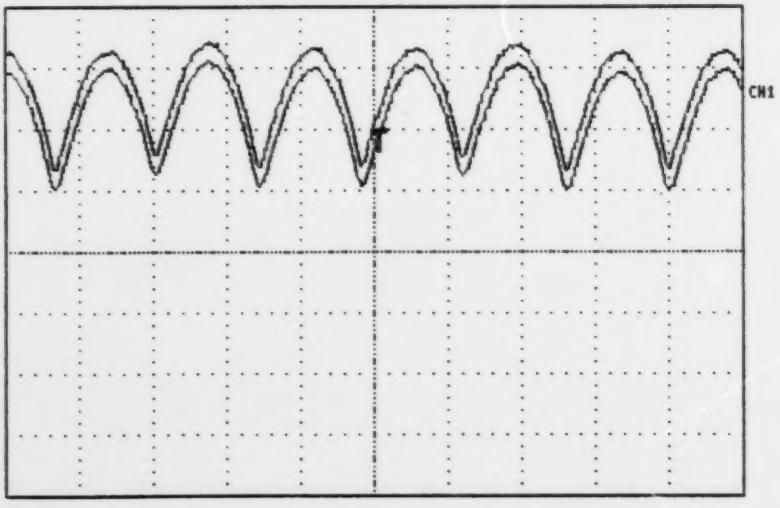
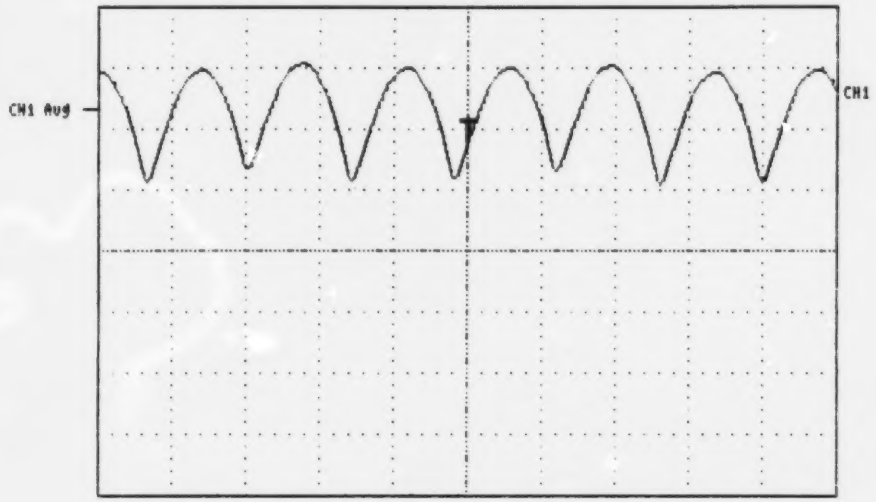


Figure C84 Light intensty @ 300 A. (18 in. up; 25 in. right)

CH1 5 mVΩ (Avg 42.2 mV, Max 46.8 mV, Min 36.8 mV, Rip 23.7%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(7): δMax 4.20 mV(9.9%), δAvg 2.77 mV(6.6%))
(Minima(7): δMax 5.60 mV(13.3%), δAvg 3.86 mV(7.2%))
A 2 ms 50.30 V LINE Env:256

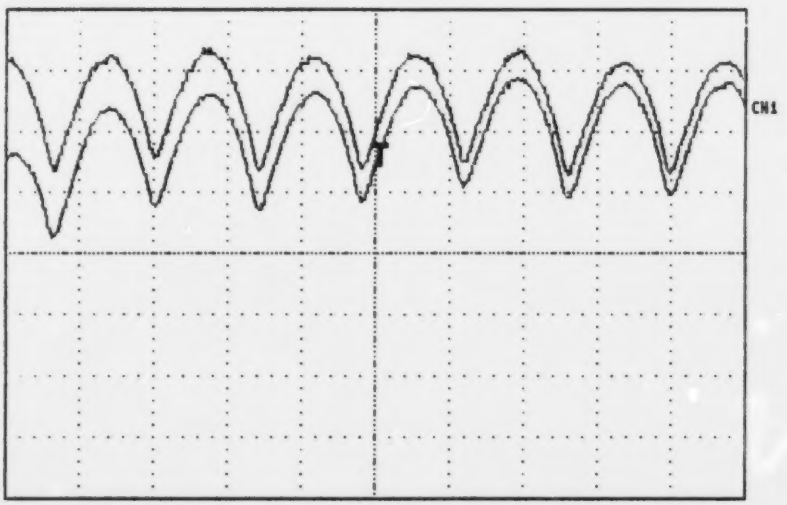
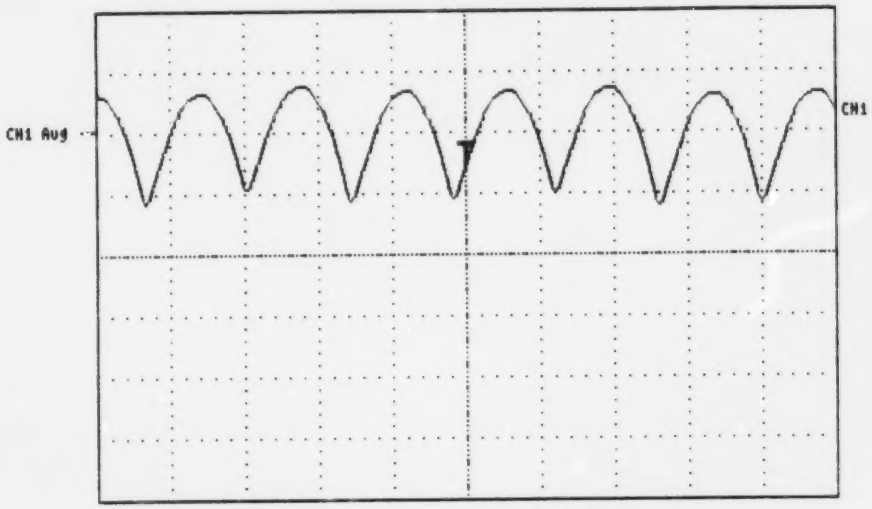


Figure C85 Light intensty @ 300 A. (18 in. up; 33 in. right)

CH1 5 mVΩ (Avg 40.8 mV, Max 44.4 mV, Min 34.6 mV, Rip 24.0%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(7): δMax 1.80 mV(4.4%), δAvg 1.60 mV(3.9%))
(Minima(7): δMax 1.60 mV(3.9%), δAvg 1.51 mV(3.7%))
A 2 ms 50.30 V LINE Env:256

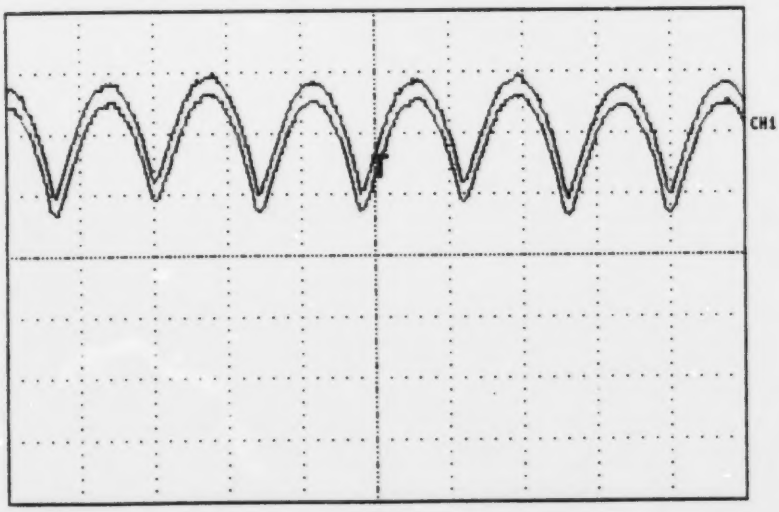
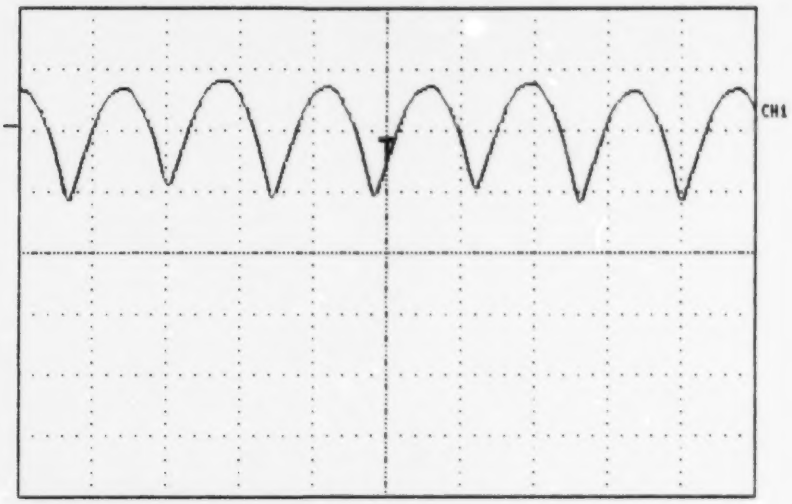


Figure C86 Light intensty @ 300 A. (18 in. up; 46 in. right)

CH1 5 mVΩ (Avg 41.0 mV, Max 44.6 mV, Min 34.8 mV, Rip 23.9%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(6): δMax 1.88 mV(4.4%), δAvg 1.53 mV(3.7%))
(Minima(7): δMax 1.88 mV(4.4%), δAvg 1.54 mV(3.8%))
A 2 ms 50.30 V LINE Env:256

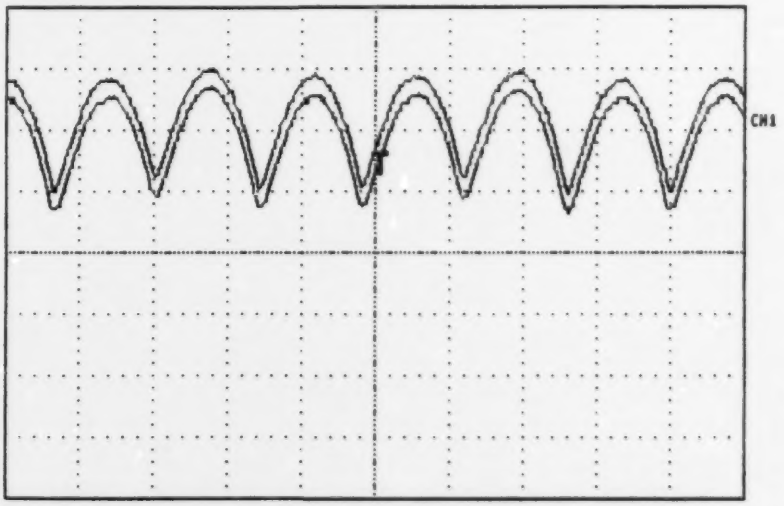
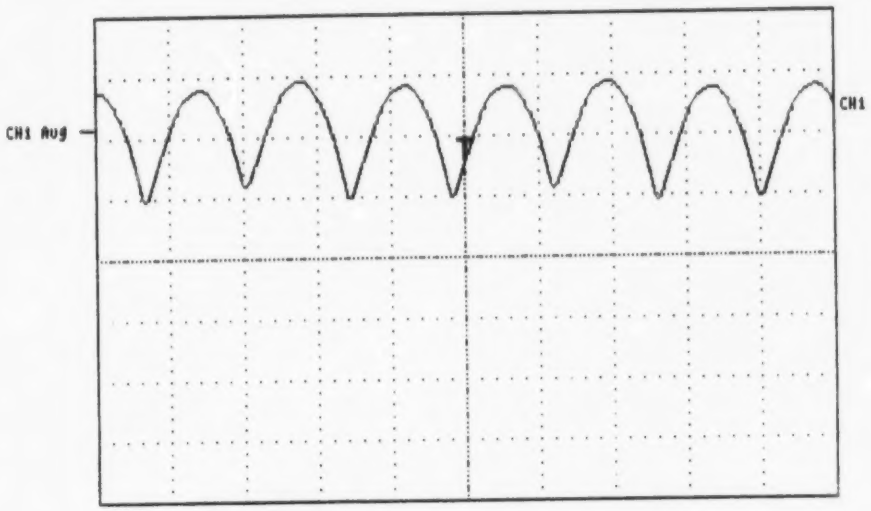


Figure C87 Light intensty @ 300 A. (12 in. up; 46 in. right)

CH1 5 mVΩ (Avg 41.4 mV, Max 45.2 mV, Min 35.2 mV, Rip 24.1%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(7): δMax 7.20 mV(17.4%), δAvg 2.66 mV(6.4%))
(Minima(7): δMax 5.40 mV(13.8%), δAvg 2.23 mV(5.4%))
A 2 ms 50.30 V LINE Env:256

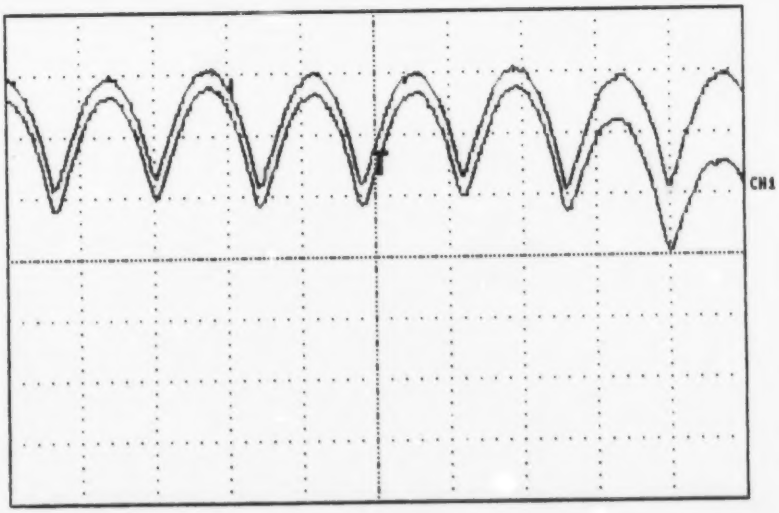
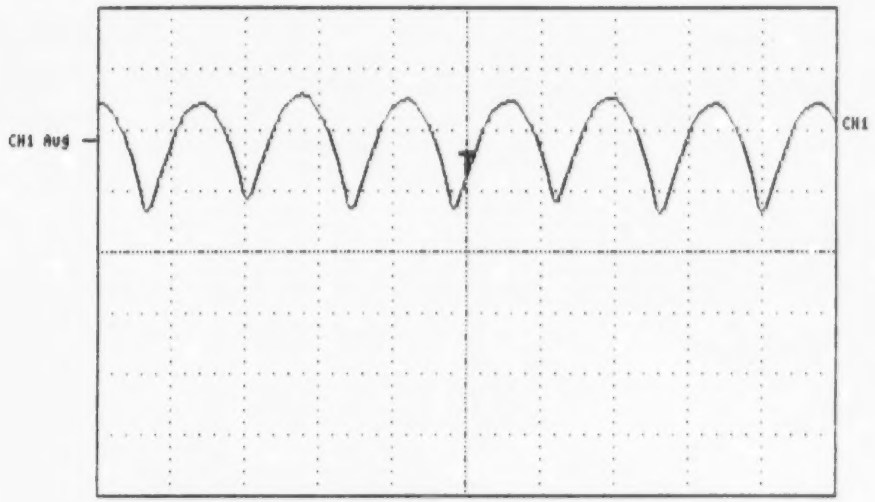


Figure C88 Light intensty @ 300 A. (6 in. up; 46 in. right)

CH1 5 mVΩ (Avg 39.8 mV, Max 43.6 mV, Min 33.8 mV, Rip 24.6%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(6): δMax 1.80 mV(4.5%), δAvg 1.60 mV(4.0%))
(Minima(7): δMax 1.60 mV(4.0%), δAvg 1.51 mV(3.8%))
A 2 ms 50.30 V LINE Env:256

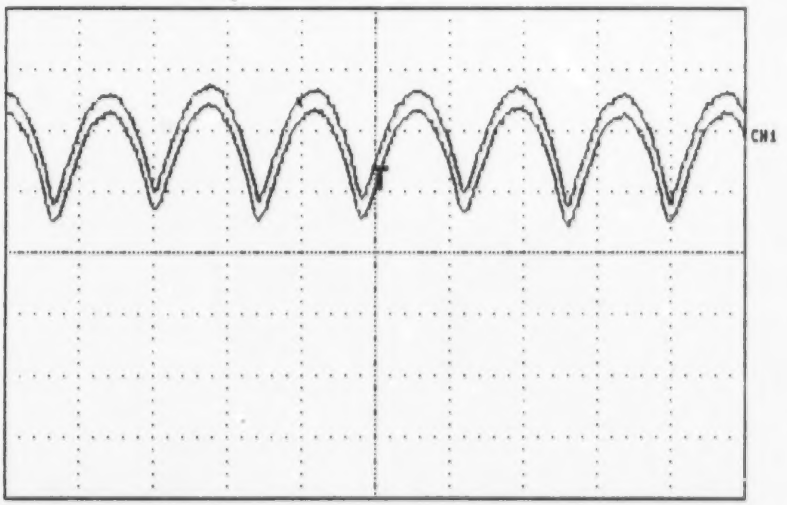
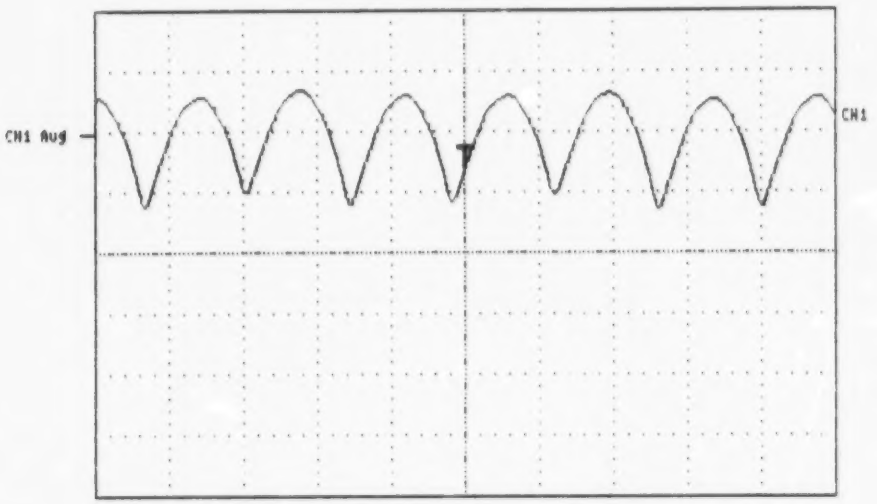


Figure C89 Light intensty @ 300 A. (24 in. up; 46 in. right)

CH1 5 mVΩ (Avg 40.3 mV, Max 44.0 mV, Min 34.2 mV, Rip 24.3%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(7): δMax 2.00 mV(5.0%), δAvg 1.77 mV(4.4%))
(Minima(7): δMax 2.40 mV(6.0%), δAvg 1.94 mV(4.8%))
A 2 ms 50.30 V LINE Env:256

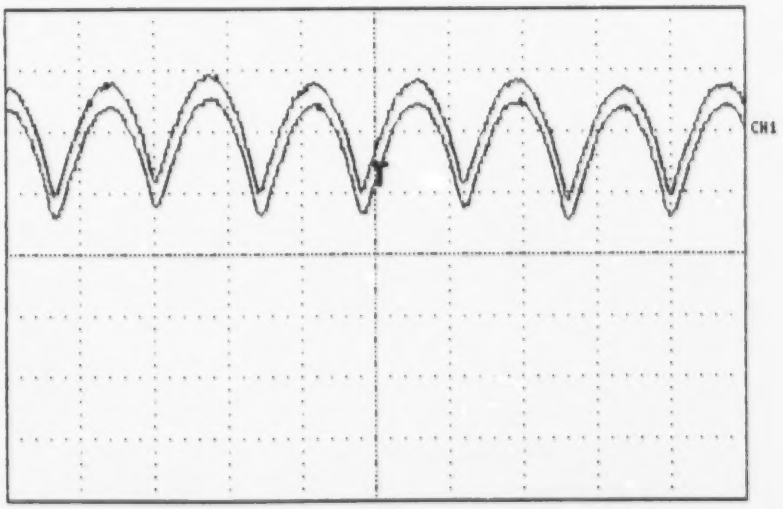
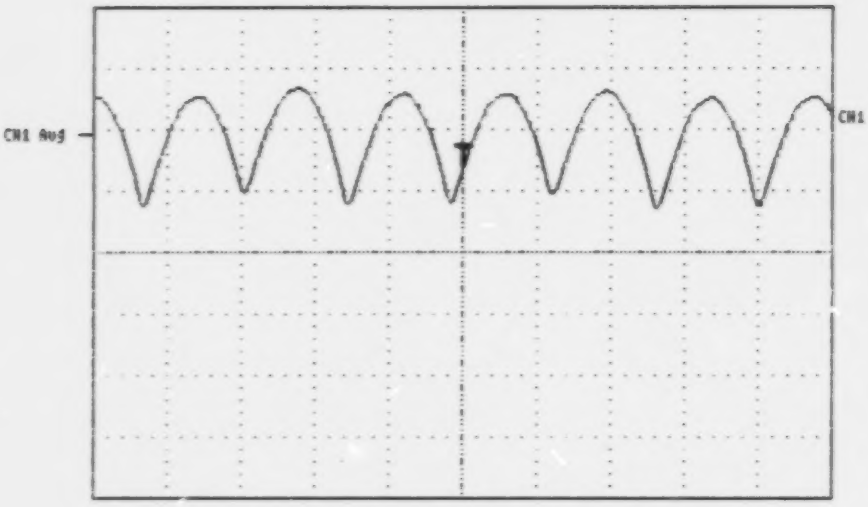
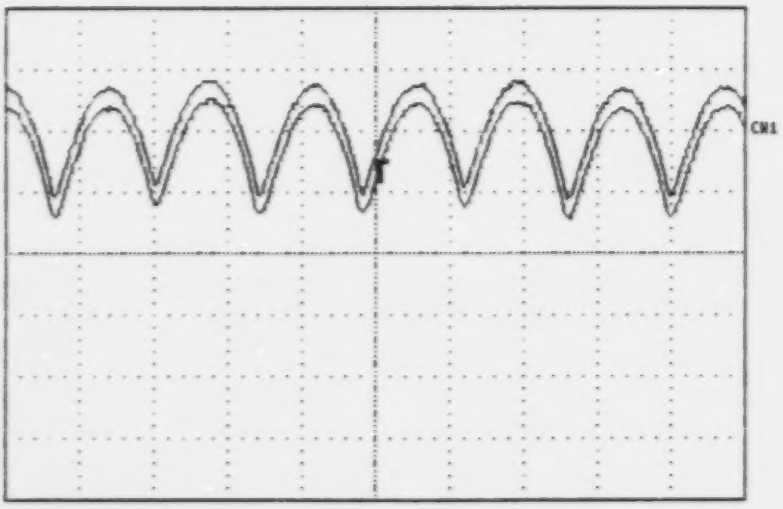


Figure C98 Light intensty @ 300 A. (24 in. up; 46 in. right)

CH1 5 mVΩ (Avg 48.3 mV, Max 44.8 mV, Min 34.2 mV, Rip 24.3%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(7): δMax 1.60 mV(4.8%), δAvg 1.57 mV(3.9%))
(Minima(7): δMax 1.60 mV(4.8%), δAvg 1.54 mV(3.8%))
A 2 ms 50.30 V LINE Env:256



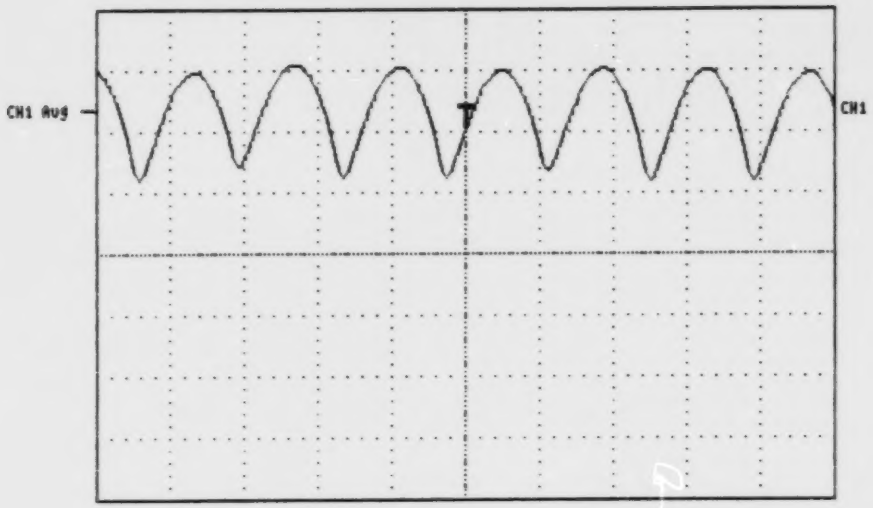
APPENDIX C

Table C6. Summary of data for the arc intensity at 350 Amps.

Figure (#)	Position to center right (in.)	up (in.)	Ripple (%)	Maxima max. (%)	Maxima avg. (%)	Minima max. (%)	Minima avg. (%)
C91	0	6	17.1	4.0	3.7	4.0	3.5
C92	0	18	16.4	3.3	3.1	3.6	3.0
C93	-12	18	16.6	5.3	4.8	6.4	5.6
C94	-26	18	16.1	5.4	4.9	5.4	4.9
C95	-37	18	15.9	4.7	3.8	4.7	4.2
C96	-49	18	17.1	6.1	5.5	6.5	6.1
C97	-57	18	16.7	4.3	3.6	4.3	3.9
C98	-57	12	16.4	4.0	3.7	4.4	3.8
C99	-57	6	16.9	6.1	5.3	7.3	5.6
C100	-57	24	16.5	3.8	3.6	4.2	4.0
C101	13	18	16.2	3.5	3.1	3.5	3.2
C102	25	18	16.6	5.8	4.3	5.8	4.1
C103	33	18	16.4	3.6	3.3	3.6	3.4
C104	46	18	16.4	4.8	4.2	5.2	4.5
C105	46	12	16.1	4.7	4.3	4.7	4.4
C106	46	6	16.4	6.4	5.6	6.8	5.9
C107	46	24	16.2	23.1	8.3	18.2	9.2
C108	46	24	16.7	4.1	3.5	3.7	3.4
Average			16.48	5.72	4.37	5.68	4.59
Std. Dev.			0.32	4.32	1.23	3.25	1.45

Figure C91 Light intensty @ 350 A. (6 in. up; center)

CH1 5 mVΩ (Avg 55.0 mV, Max 58.6 mV, Min 49.2 mV, Rip 17.1%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(7): δMax 2.20 mV(4.0%), δAvg 2.03 mV(3.7%))
(Minima(7): δMax 2.20 mV(4.0%), δAvg 1.91 mV(3.5%))
A 2 ms 50.30 V LINE Env:256

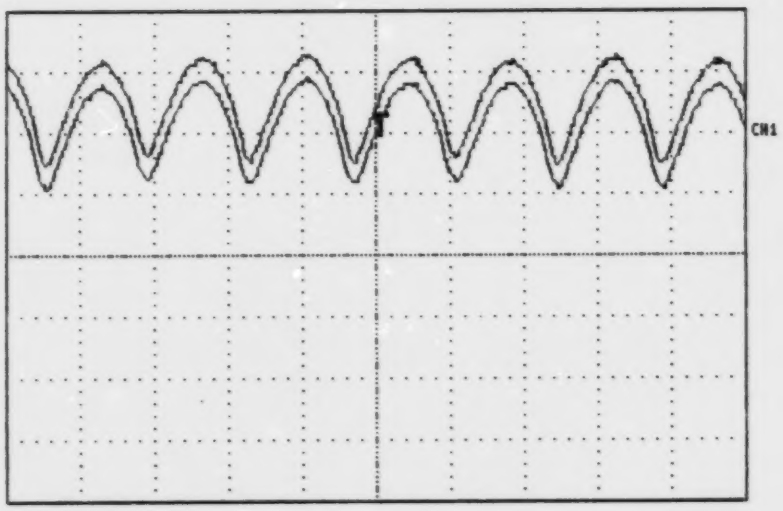
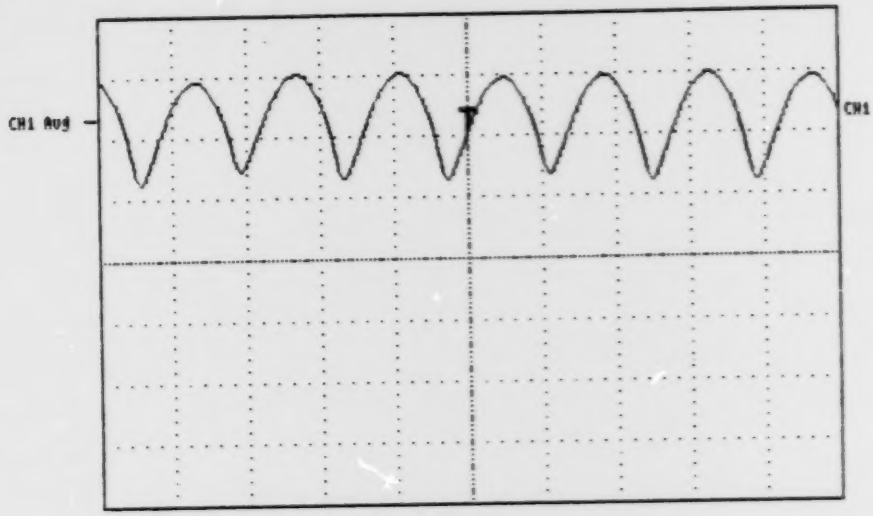


Figure C92 Light intensty @ 350 A. (18 in. up; center)

CH1 5 mV/ (Avg 54.9 mV, Max 58.4 mV, Min 49.4 mV, Rip 16.4%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mV/ (Maxima(7): δMax 1.80 mV(3.3%), δAvg 1.71 mV(3.1%))
(Minima(7): δMax 2.80 mV(3.6%), δAvg 1.66 mV(3.8%))
A 2 ms 50.30 V LINE Env:256

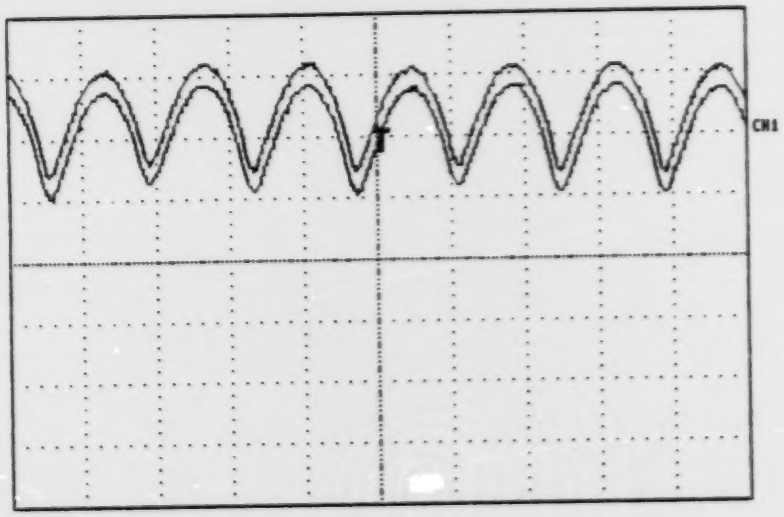
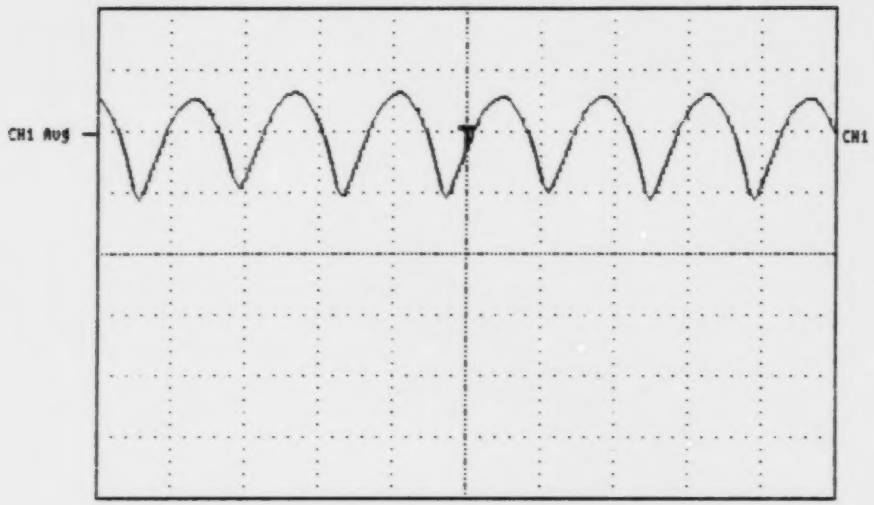


Figure C93 Light intensty @ 350 A. (18 in. up; 12 in. left)

CH1 5 mVΩ (Avg 53.8 mV, Max 56.4 mV, Min 47.6 mV, Rip 16.6%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(7): δMax 2.80 mV(5.3%), δAvg 2.54 mV(4.8%))
(Minima(7): δMax 3.40 mV(6.4%), δAvg 2.97 mV(5.6%))
A 2 ms 50.30 V LINE Env:256

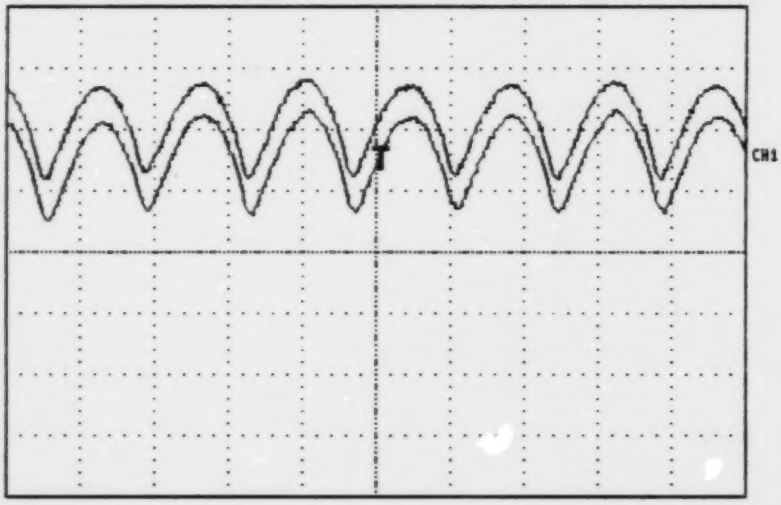
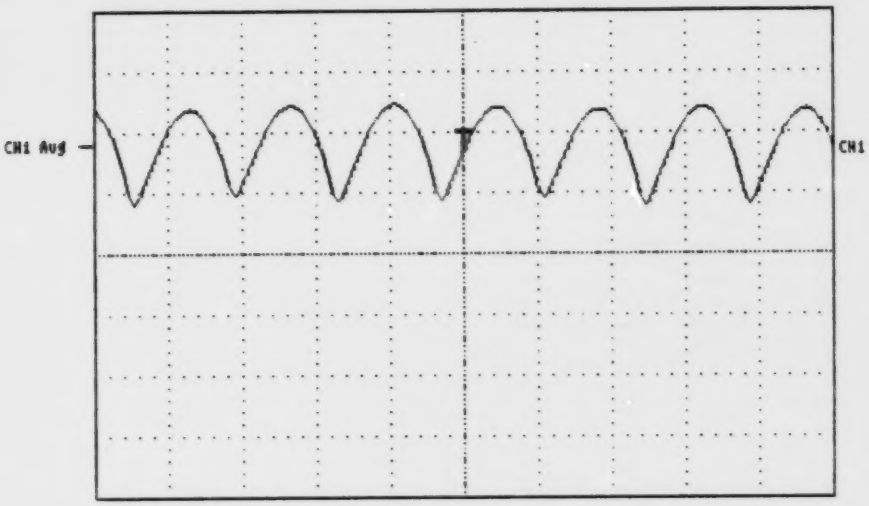


Figure C94 Light intensty @ 350 A. (18 in. up; 26 in. left)

CH1 5 mVΩ (Avg 52.3 mV, Max 55.6 mV, Min 47.2 mV, Rip 16.1%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(7): δMax 2.80 mV(5.4%), δAvg 2.54 mV(4.9%))
(Minima(7): δMax 2.80 mV(5.4%), δAvg 2.54 mV(4.9%))
A 2 ms 50.30 V LINE Env:256

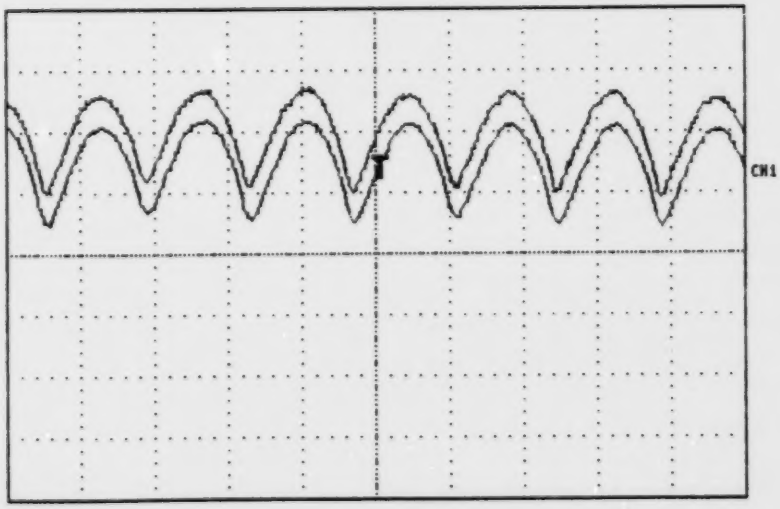
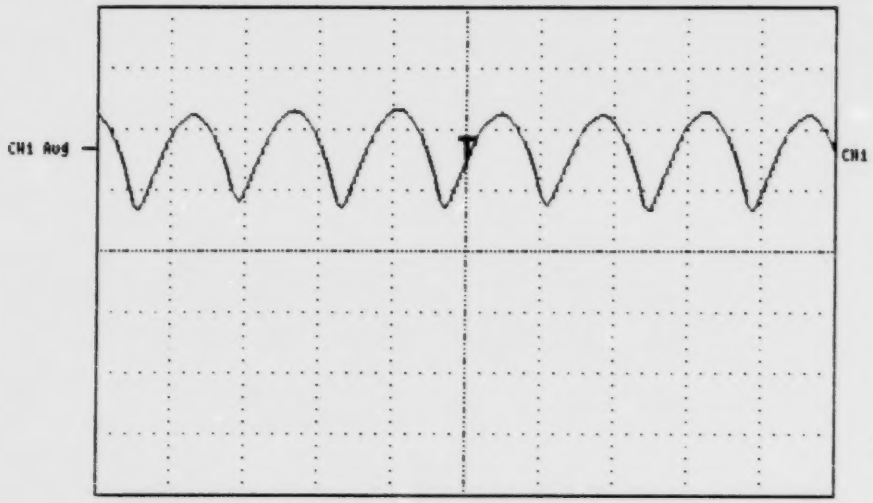


Figure C95 Light intensty @ 350 A. (18 in. up; 37 in. left)

CH1 5 mVΩ (Avg 51.5 mV, Max 54.8 mV, Min 46.6 mV, Rip 15.9%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(7): δMax 2.40 mV(4.7%), δAvg 1.97 mV(3.8%))
(Minima(7): δMax 2.40 mV(4.7%), δAvg 2.14 mV(4.2%))
A 2 ms 50.30 V LINE Env:256

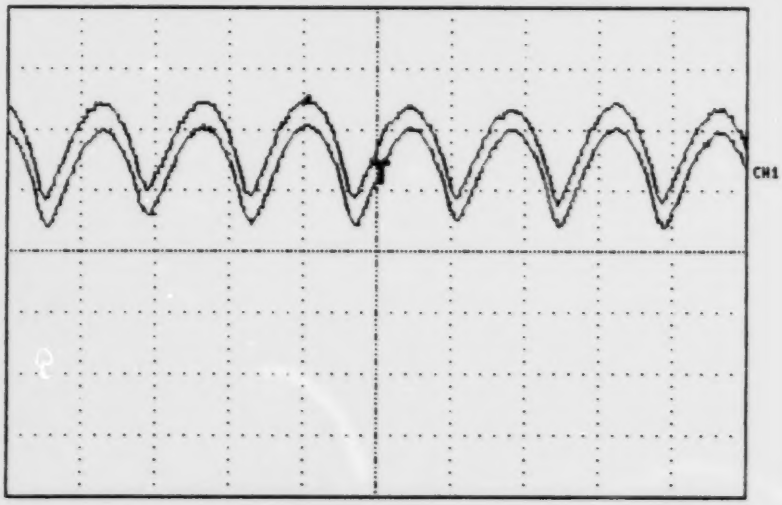
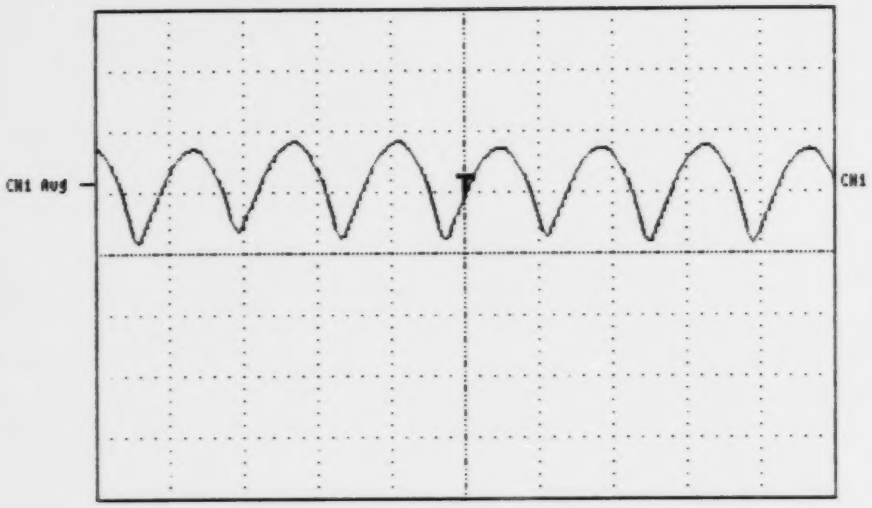


Figure C96 Light intensty @ 350 A. (18 in. up; 49 in. left)

CH1 5 mVΩ (Avg 49.1 mV, Max 52.4 mV, Min 44.8 mV, Rip 17.1%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(7): δMax 3.80 mV(6.1%), δAvg 2.71 mV(5.5%))
(Minima(7): δMax 3.20 mV(6.5%), δAvg 3.80 mV(6.1%))
A 2 ms 50.30 V LINE Env:256

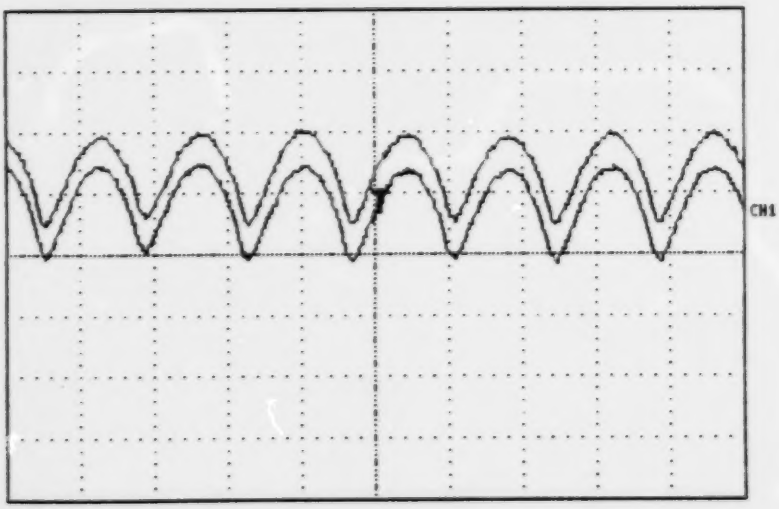
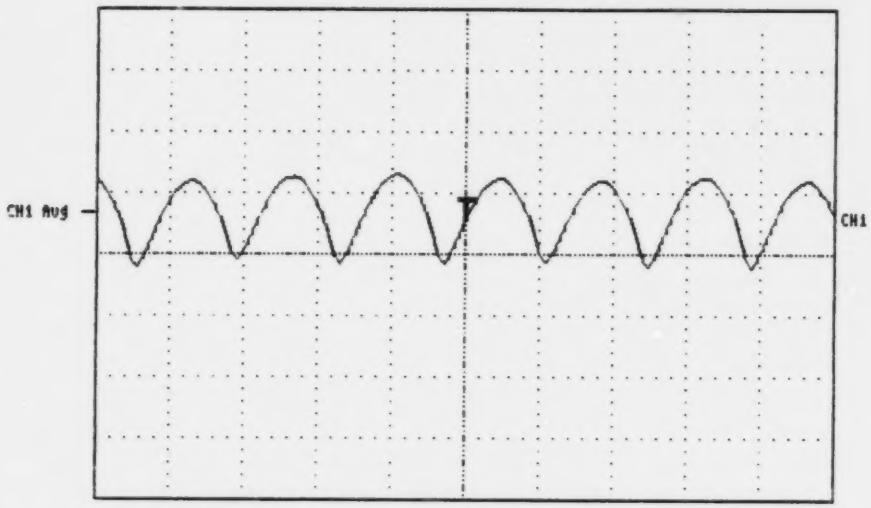


Figure C97 Light intensty @ 350 A. (18 in. up; 57 in. left)

CH1 5 mVΩ (Avg 46.7 mV, Max 49.8 mV, Min 42.8 mV, Rip 16.7%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(7): δMax 2.00 mV(4.3%), δAvg 1.69 mV(3.6%))
(Minima(7): δMax 2.00 mV(4.3%), δAvg 1.80 mV(3.9%))
A 2 ms 50.30 V LINE Env:256

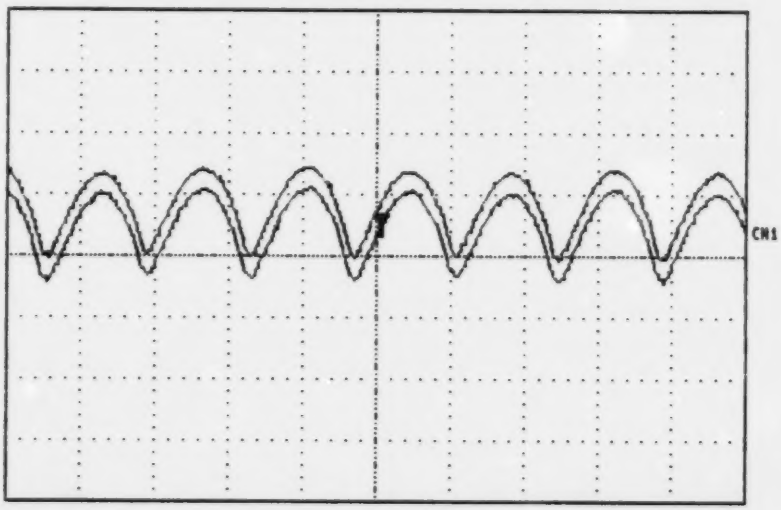
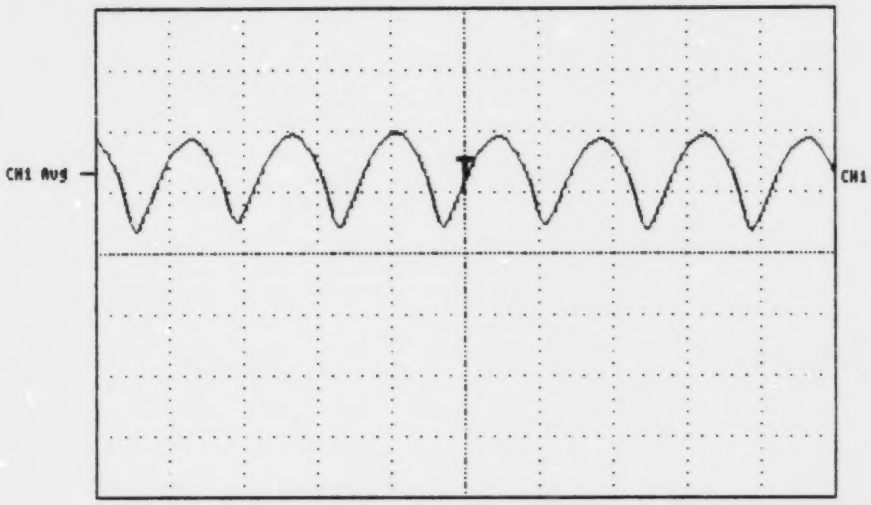


Figure C98 Light intensty @ 350 A. (12 in. up; 57 in. left)

CH1 5 mVΩ (Avg 49.9 mV, Max 53.2 mV, Min 45.8 mV, Rip 16.4%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(7): δMax 2.00 mV(4.0%), δAvg 1.86 mV(3.7%))
(Minima(7): δMax 2.20 mV(4.4%), δAvg 1.89 mV(3.8%))
A 2 ms 50.30 V LINE Env:256

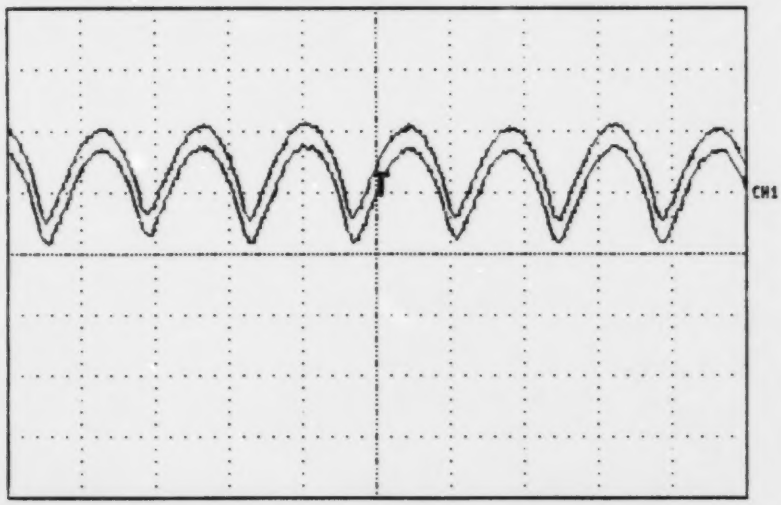
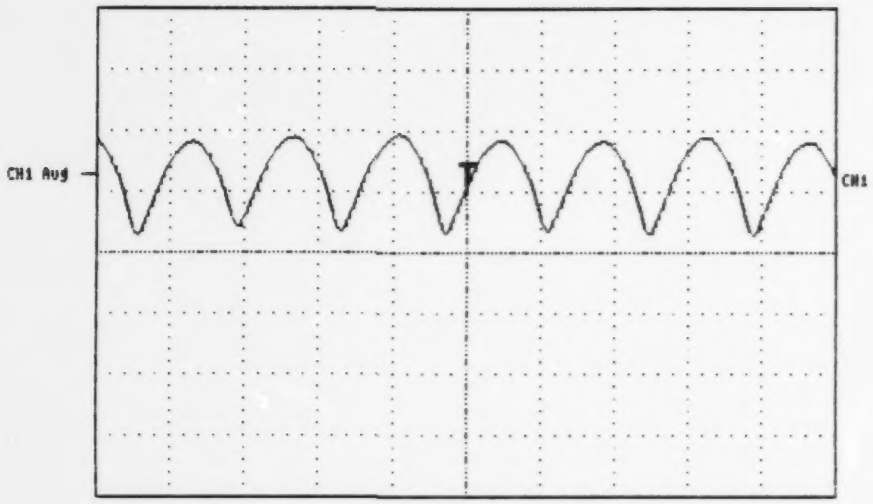


Figure C99 Light intensty @ 350 A. (6 in. up; 57 in. left)

CH1 5 mVΩ (Avg 49.6 mV, Max 53.0 mV, Min 44.6 mV, Rip 16.9%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(7): δMax 3.80 mV(6.1%), δAvg 2.63 mV(5.3%))
(Minima(7): δMax 3.60 mV(7.3%), δAvg 2.80 mV(5.6%))
A 2 ms 50.30 V LINE Env:256

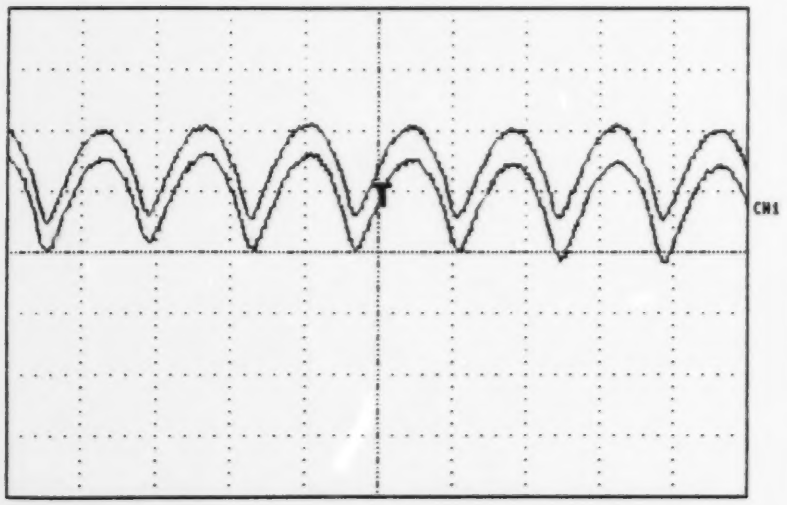
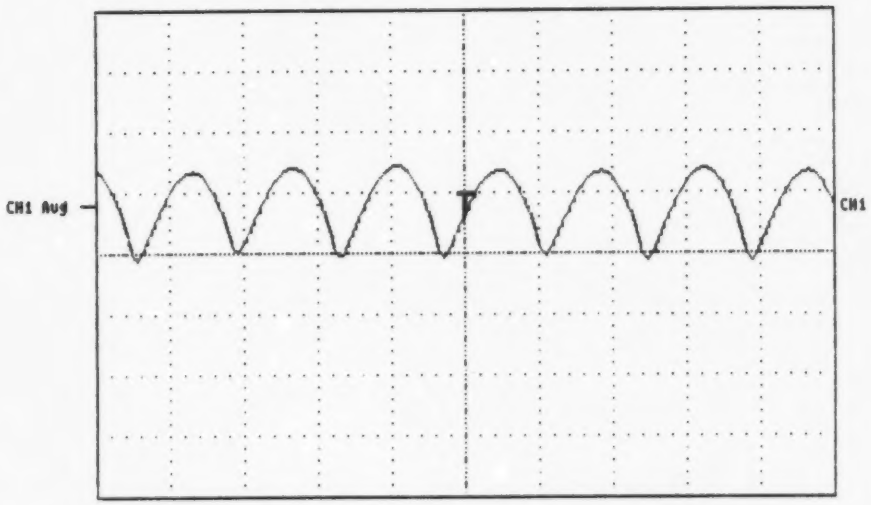


Figure C100 Light intensty @ 350 A. (24 in. up; 57 in. left)

CH1 5 mVΩ (Avg 47.3 mV, Max 50.4 mV, Min 42.6 mV, Rip 16.5%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(7): δMax 1.88 mV(3.8%), δAvg 1.69 mV(3.6%))
(Minima(7): δMax 2.88 mV(4.2%), δAvg 1.89 mV(4.0%))
A 2 ms 50.30 V LINE Env:256

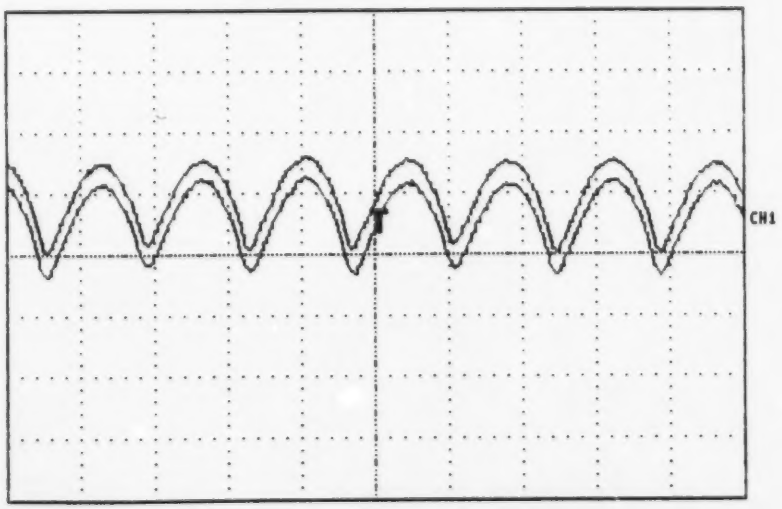
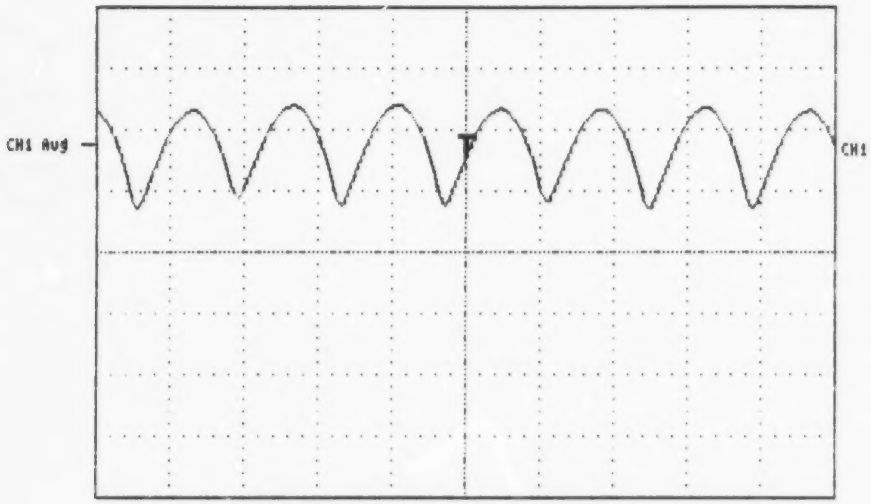


Figure C101 Light intensty @ 350 A. (18 in. up; 13 in. right)

CH1 5 mV Ω (Avg 51.9 mV, Max 55.2 mV, Min 46.8 mV, Rip 16.2%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mV Ω (Maxima(7): δMax 1.80 mV(3.5%), δAvg 1.60 mV(3.1%))
(Minima(7): δMax 1.80 mV(3.5%), δAvg 1.66 mV(3.2%))
A 2 ms 50.30 V LINE Env:256

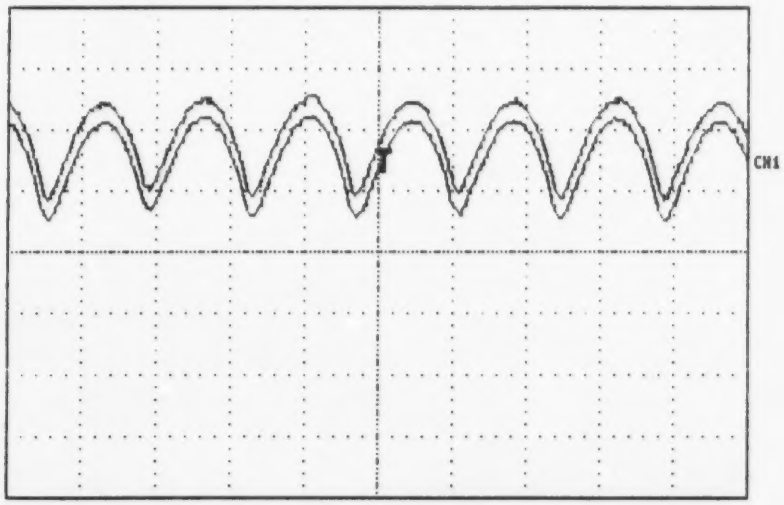
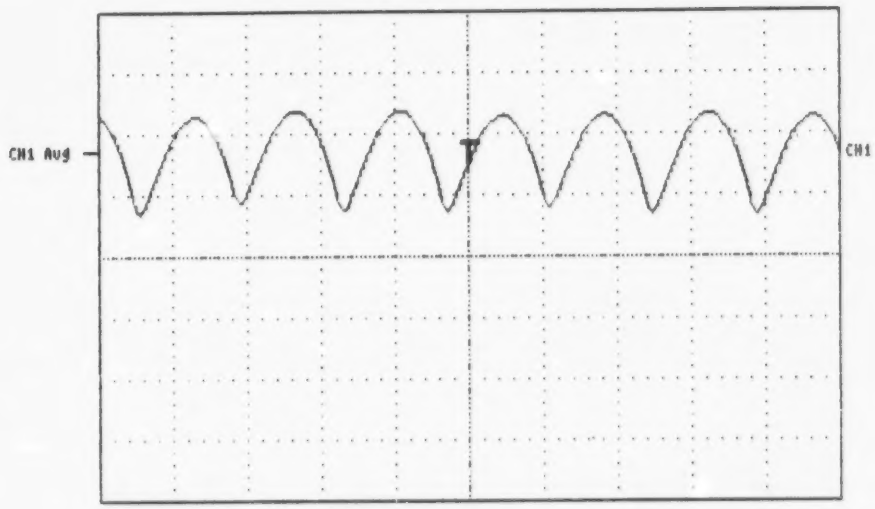


Figure C102 Light intensty @ 350 A. (18 in. up; 25 in. right)

CH1 5 mVΩ (Avg 51.8 mV, Max 55.2 mV, Min 46.6 mV, Rip 16.6%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(7): δMax 3.00 mV(5.8%), δAvg 2.23 mV(4.3%))
(Minima(7): δMax 3.00 mV(5.8%), δAvg 2.14 mV(4.1%))
A 2 ms 50.30 V LINE Env:256

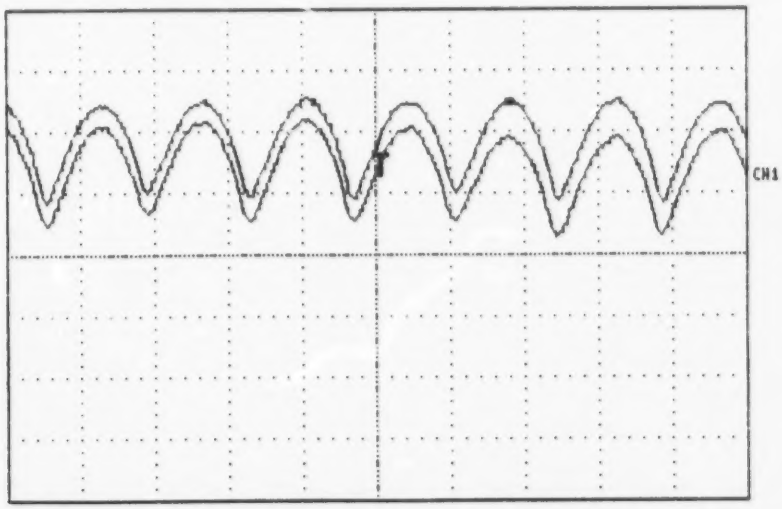
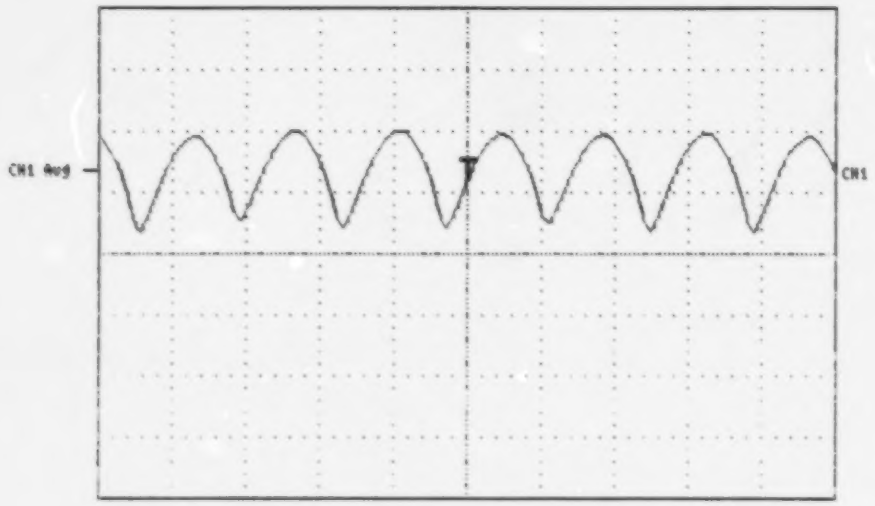


Figure C103 Light intensty @ 350 A. (18 in. up; 33 in. right)

CH1 5 mVΩ (Avg 50.0 mV, Max 53.2 mV, Min 45.0 mV, Rip 16.4%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(7): δMax 1.80 mV(3.6%), δAvg 1.66 mV(3.3%))
(Minima(7): δMax 1.80 mV(3.6%), δAvg 1.69 mV(3.4%))
A 2 ms 50.30 V LINE Env:256

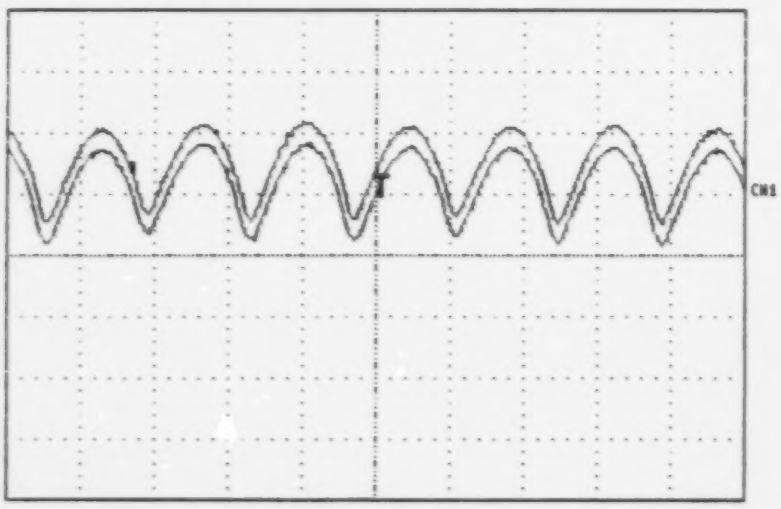
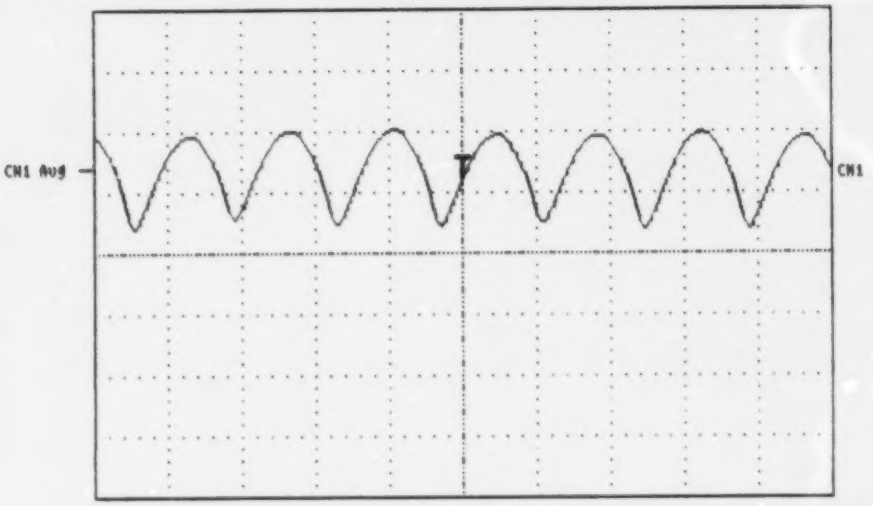


Figure C184 Light intensty @ 350 A. (18 in. up; 46 in. right)

CH1 5 mVΩ (Avg 50.1 mV, Max 53.4 mV, Min 45.2 mV, Rip 16.4%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(7): δMax 2.40 mV(4.8%), δAvg 2.11 mV(4.2%))
(Minima(7): δMax 2.60 mV(5.2%), δAvg 2.26 mV(4.5%))
A 2 ms 50.30 V LINE Env:256

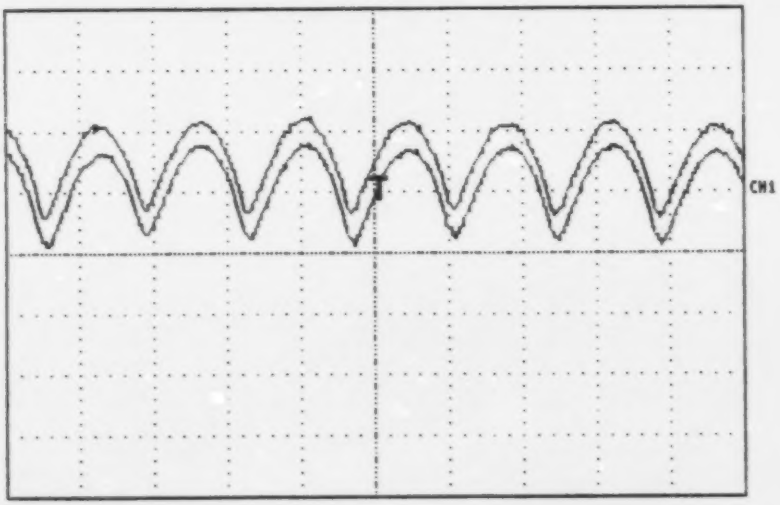
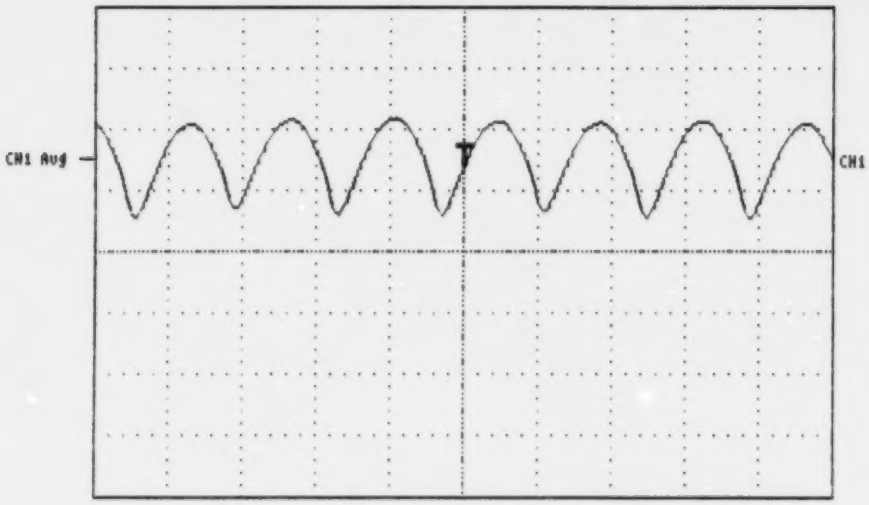


Figure C105 Light intensty @ 350 A. (12 in. up; 46 in. right)

CH1 5 mVΩ (Avg 50.9 mV, Max 54.2 mV, Min 46.0 mV, Rip 16.1%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(7): δMax 2.40 mV(4.7%), δAvg 2.20 mV(4.3%))
(Minima(7): δMax 2.40 mV(4.7%), δAvg 2.23 mV(4.4%))
A 2 ms 50.30 V LINE Env:256

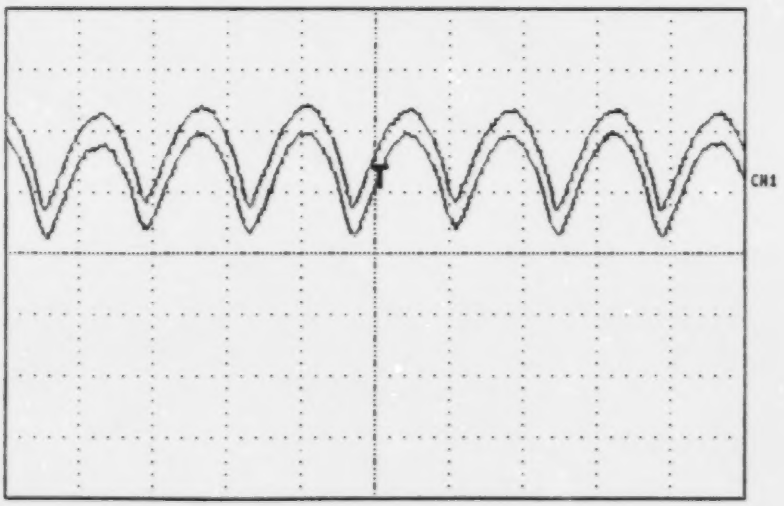
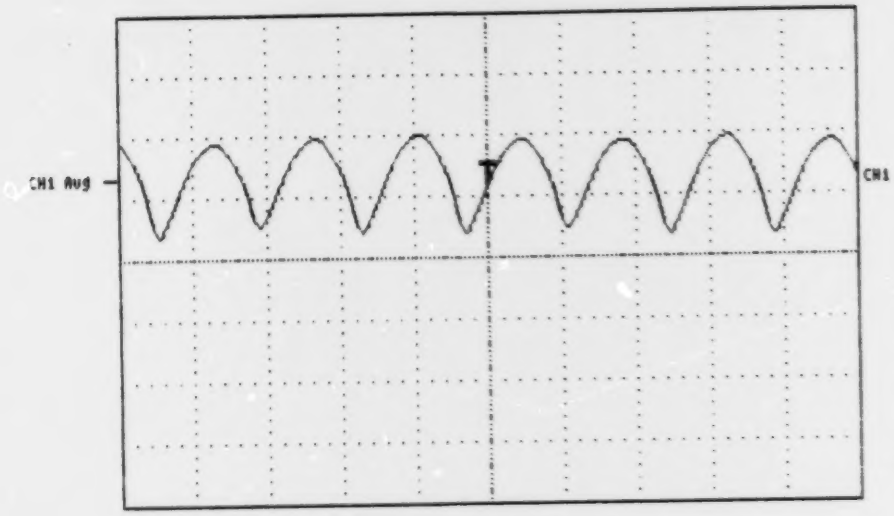


Figure C106 Light intensty @ 350 A. (6 in. up; 46 in. right)

CH1 5 mVΩ (Avg 49.9 mV, Max 53.2 mV, Min 45.8 mV, Rip 16.4%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(7): δMax 3.20 mV(6.4%), δAvg 2.77 mV(5.6%))
(Minima(7): δMax 3.40 mV(6.8%), δAvg 2.94 mV(5.9%))
A 2 ms 50.30 V LINE Env:256

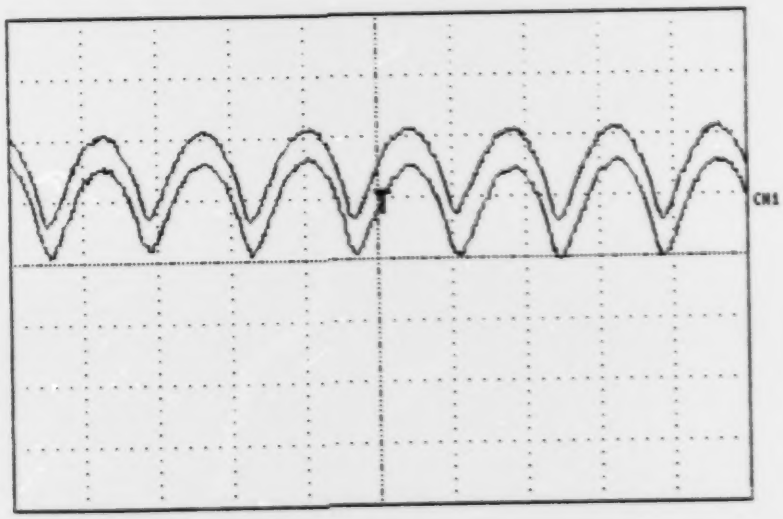
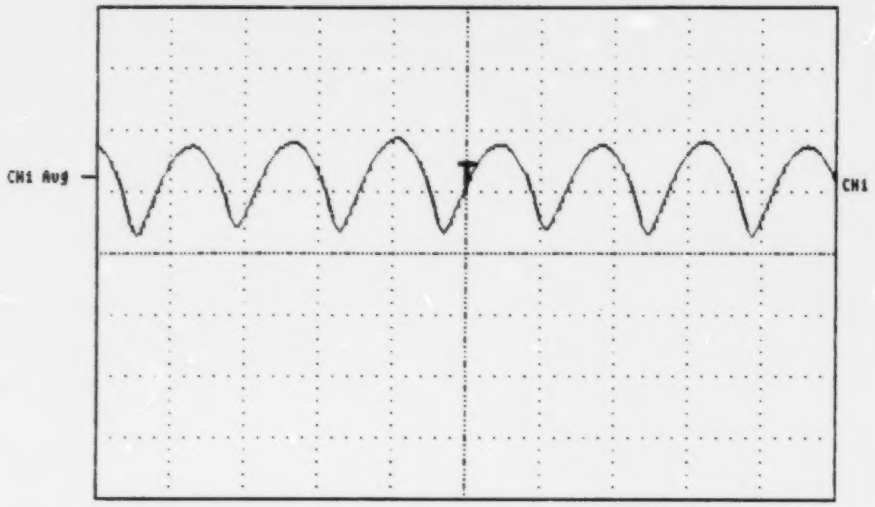


Figure C107 Light intensty @ 350 A. (24 in. up; 46 in. right)

CH1 5 mVΩ (Avg 49.3 mV, Max 52.6 mV, Min 44.6 mV, Rip 16.2%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(7): δMax 11.4 mV(23.1%), δAvg 4.89 mV(8.3%))
(Minima(7): δMax 9.00 mV(18.2%), δAvg 4.54 mV(9.2%))
A 2 ms 50.30 V LINE Env:256

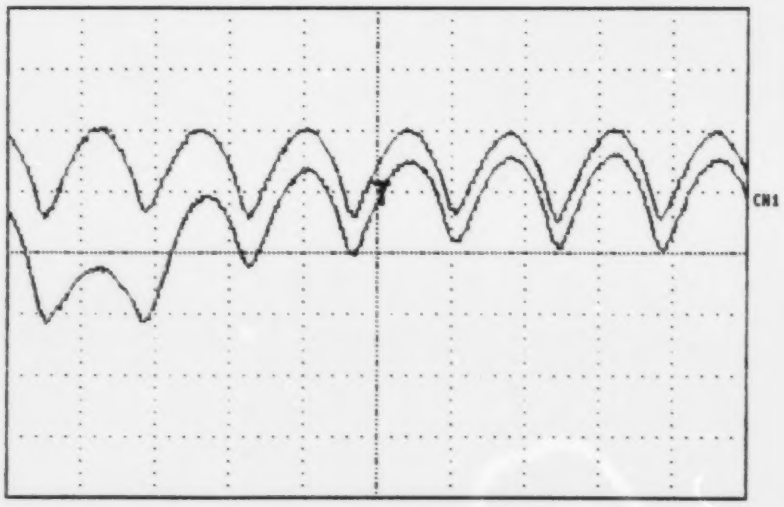
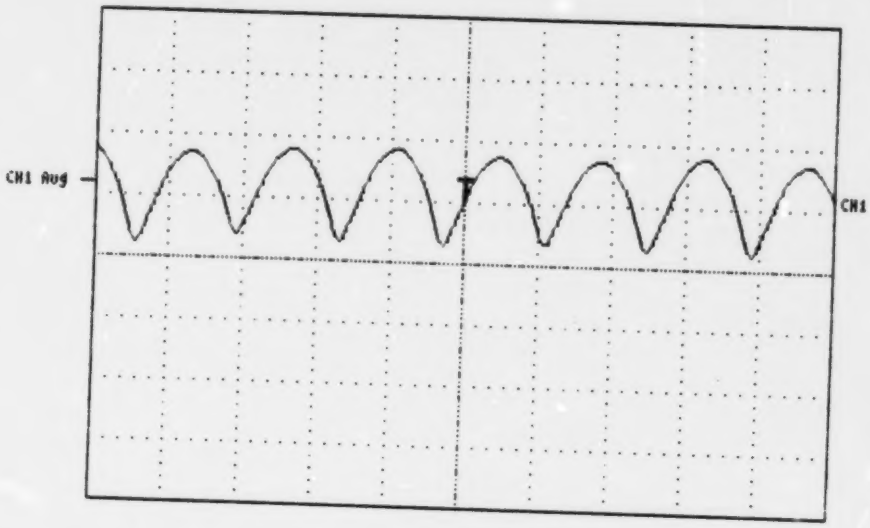


Figure C188 Light intensty @ 350 A. (24 in. up; 46 in. right)

CH1 5 mVΩ (Avg 49.2 mV, Max 52.6 mV, Min 44.4 mV, Rip 16.7%)
A 2 ms 50.30 V LINE Avg:128



CH1 5 mVΩ (Maxima(7): δMax 2.00 mV(4.1%), δAvg 1.74 mV(3.5%))
(Minima(7): δMax 1.80 mV(3.7%), δAvg 1.69 mV(3.4%))
A 2 ms 50.30 V LINE Env:256

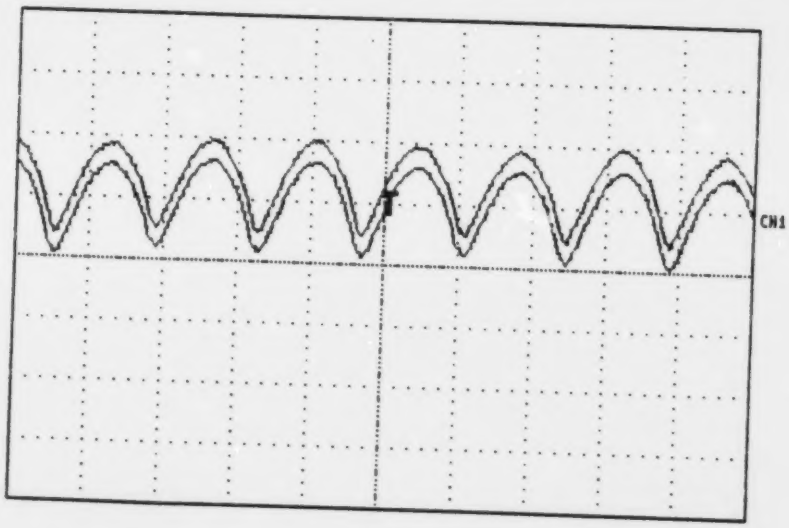
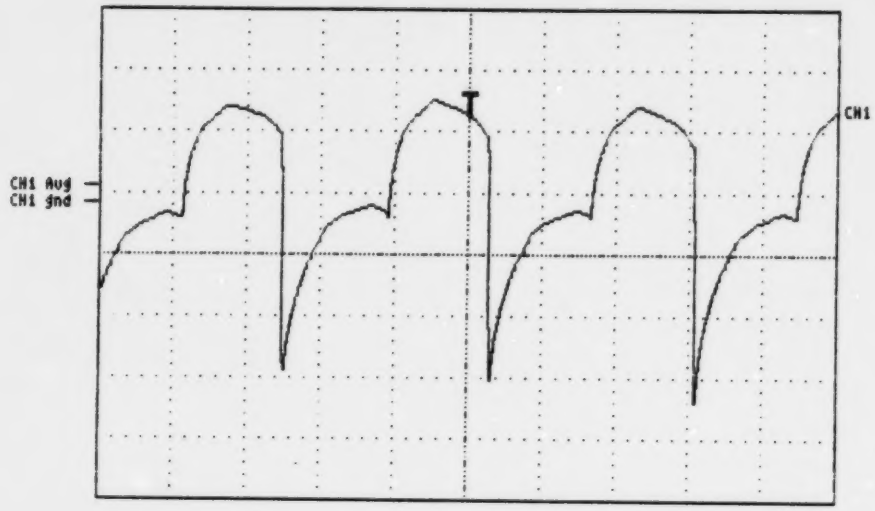


Figure C109 Arc's anode voltage at 100 Amps.

CH1 50 V (Avg 13.5 V)
A 2 ms 50.30 V LINE Avg:128



CH1 50 V
A 2 ms 50.30 V LINE Env:256

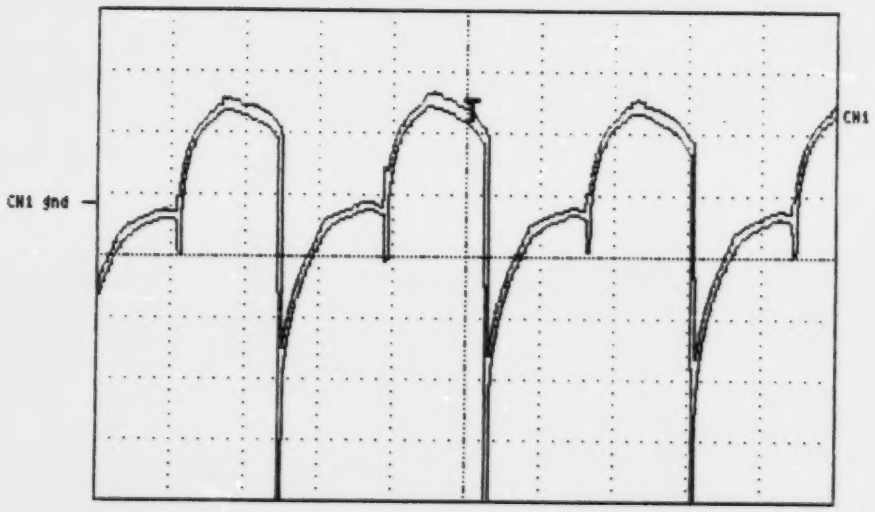
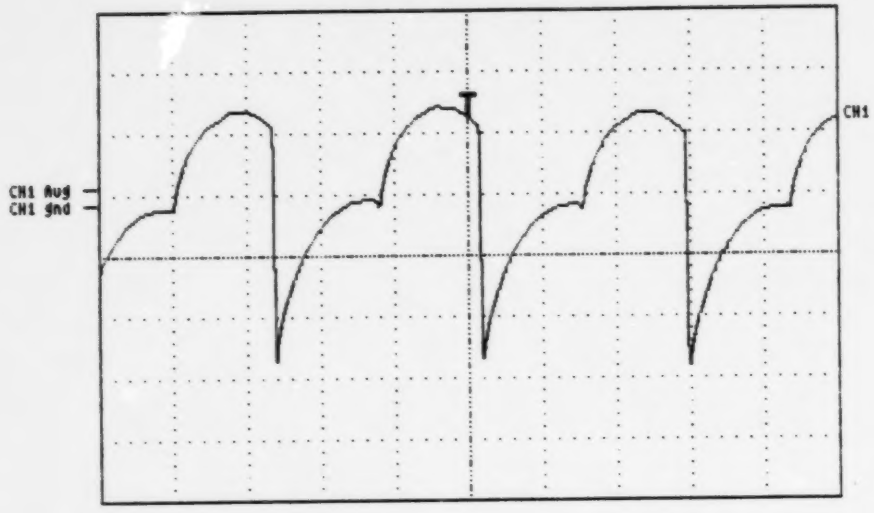


Figure C110 Arc's anode voltage at 150 Amps.

CH1 50 V (Avg 14.4 V)
A 2 ms 50.30 V LINE Avg:128



CH1 50 V
A 2 ms 50.30 V LINE Env:256

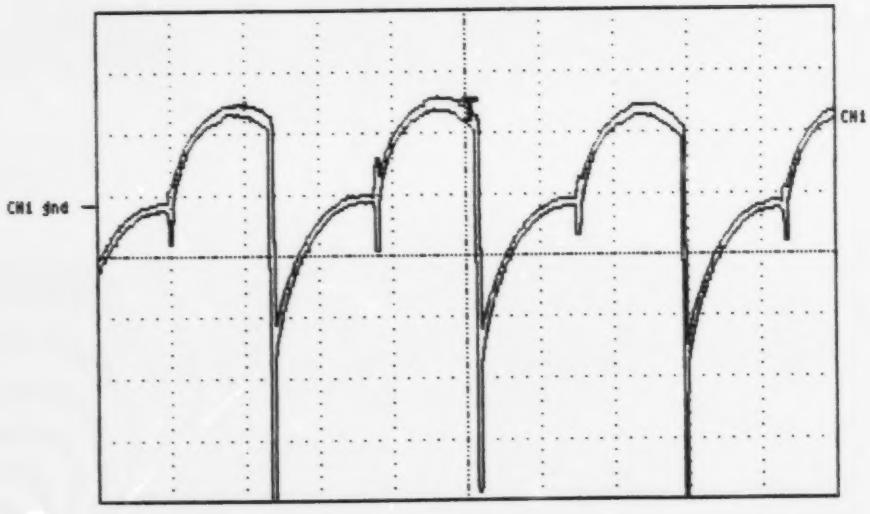


Figure C111 Arc's anode voltage at 200 Amps.

CH1 50 V (Avg 15.4 V)
A 2 ms 50.30 V LINE Avg:128

CH1 50 V
A 2 ms 50.30 V LINE Env:256

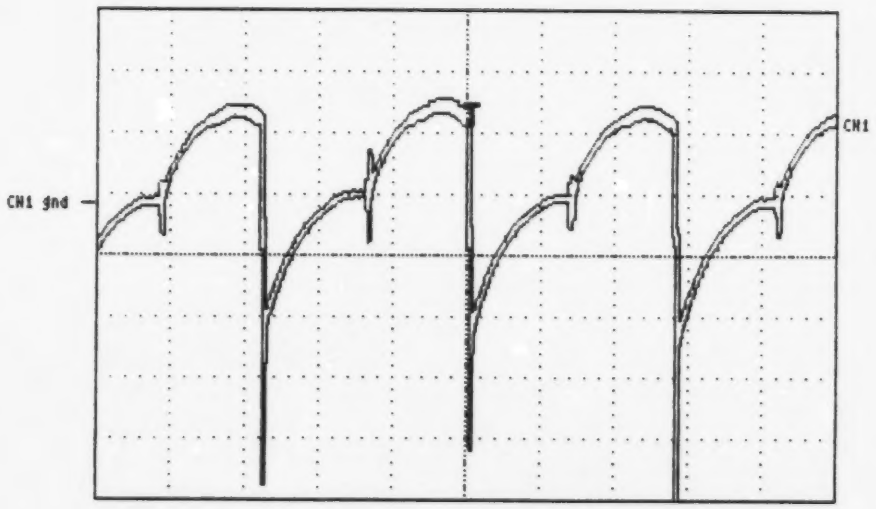
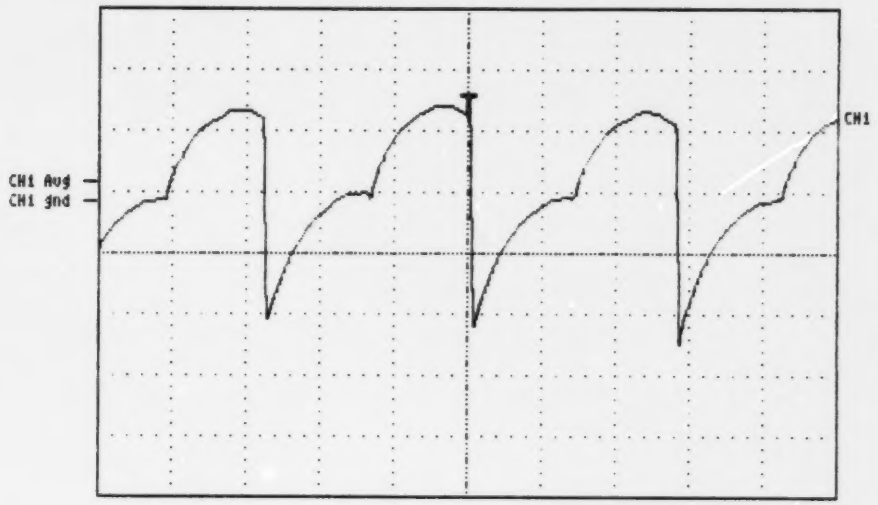


Figure C111 Arc's anode voltage at 200 Amps.

CH1 50 V (Avg 15.4 V)
A 2 ms 50.30 V LINE Avg:128



CH1 50 V
A 2 ms 50.30 V LINE Env:256

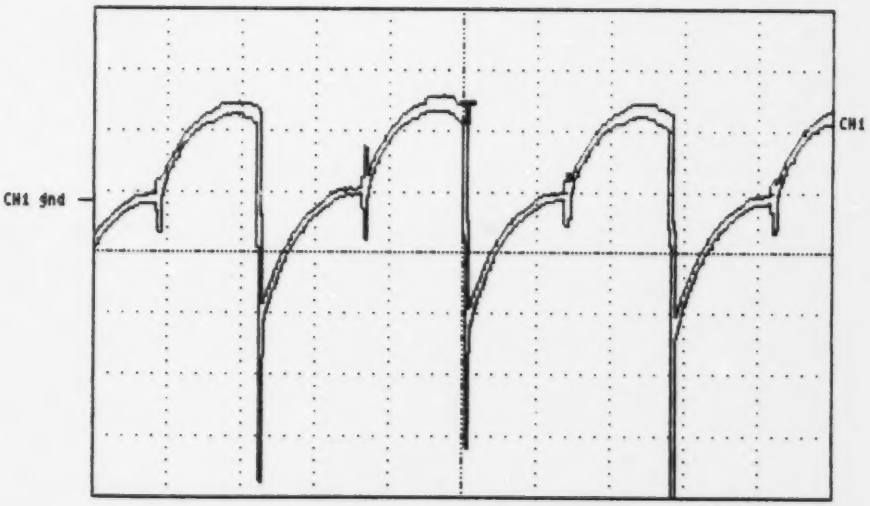
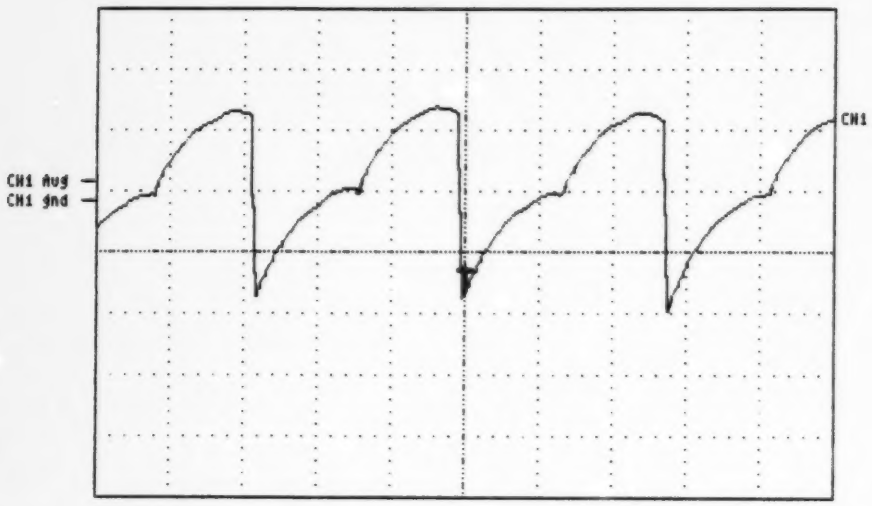


Figure C112 Arc's anode voltage at 250 Amps.

CH1 50 V (Avg 16.2 V)
A 2 ms 50.30 V LINE Avg:128



CH1 50 V
A 2 ms 50.30 V LINE Env:256

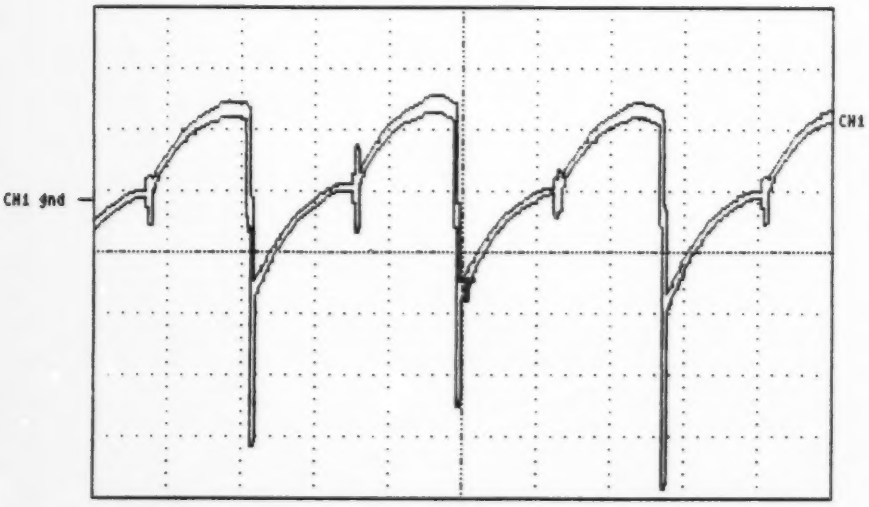


Figure C113 Arc's anode voltage at 300 Amps.

CH1 50 V (Avg 16.7 V)
A 2 ms 50.30 V LINE Avg:128

CH1 50 V
A 2 ms 50.30 V LINE Env:256

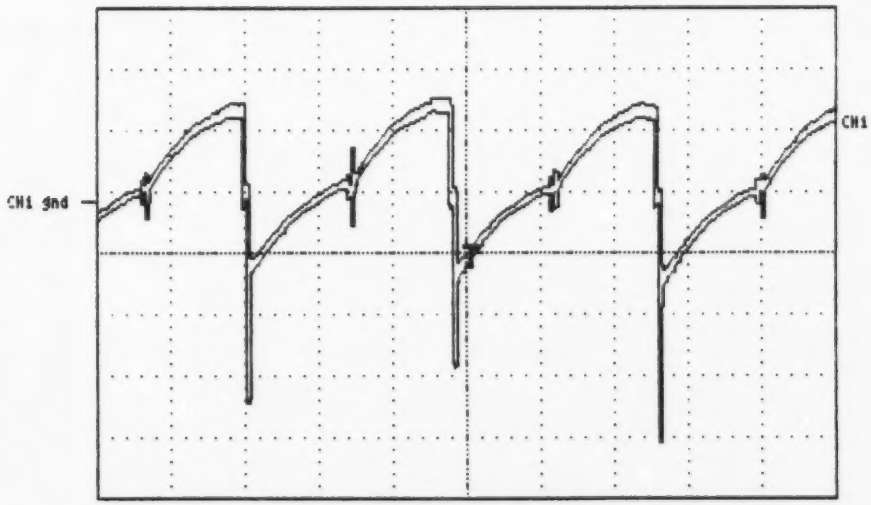


Figure C114 Arc's anode voltage at 300 Amps.

CH1 50 V (Avg 17.0 V)
A 2 ms 50.30 V LINE Avg:128

CH1 50 V
A 2 ms 50.30 V LINE Env:256

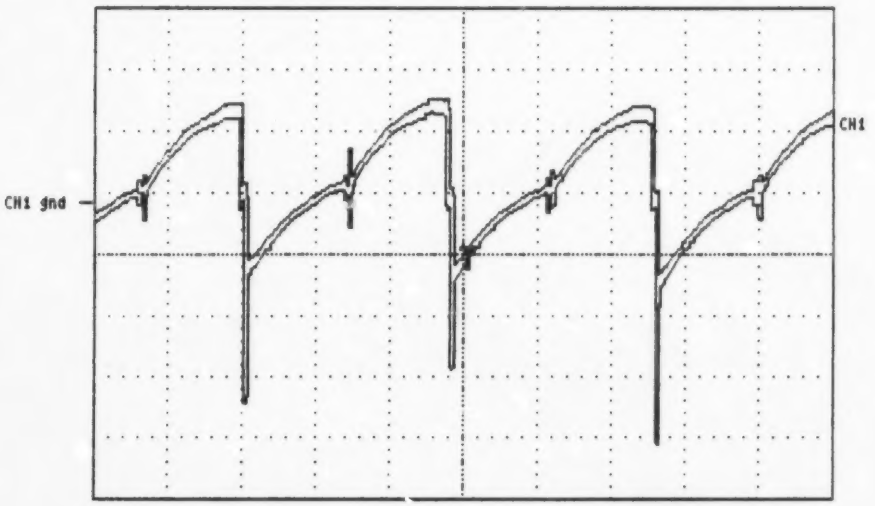
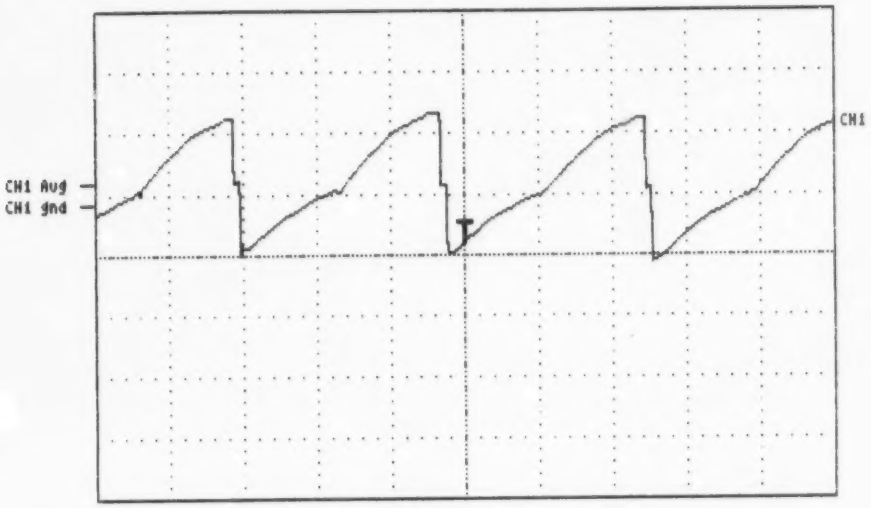


Figure C114 Arc's anode voltage at 350 Amps.

CH1 50 V (Avg 17.4 V)
A 2 ms 50.30 V LINE Avg:128



CH1 50 V
A 2 ms 50.30 V LINE Env:256

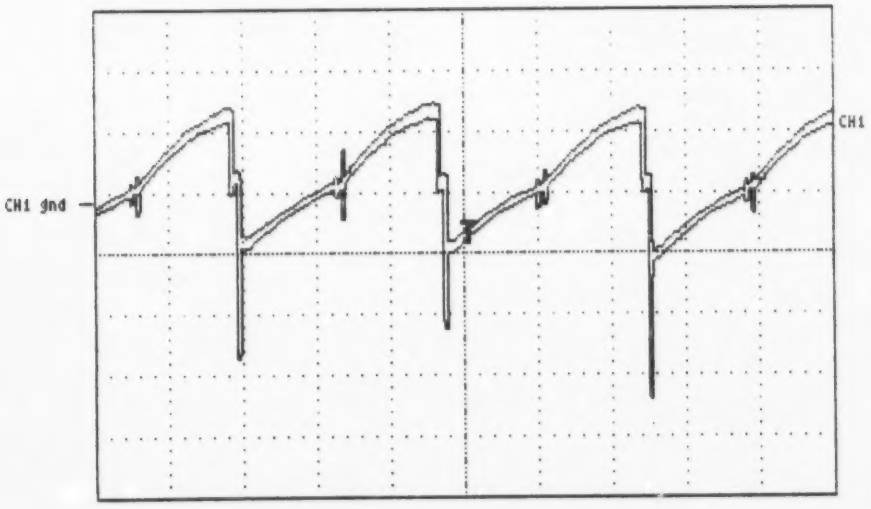
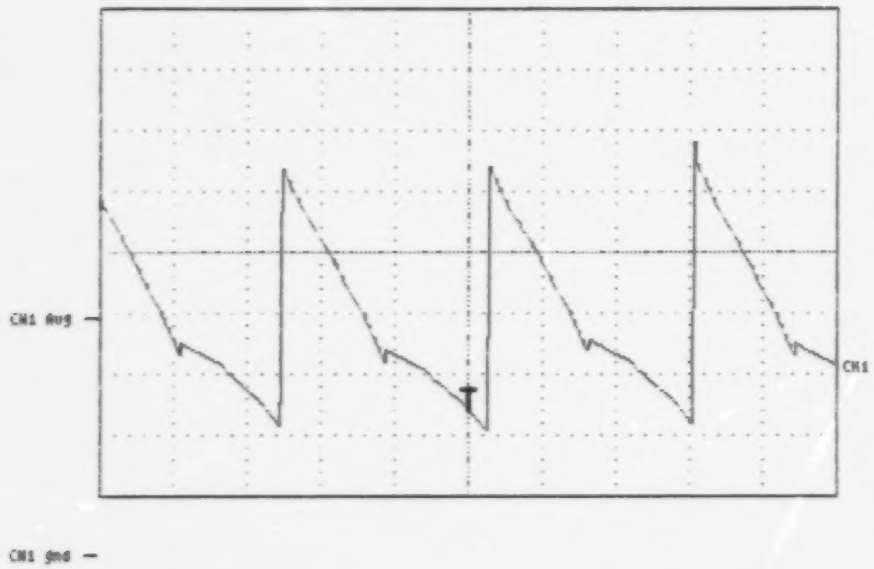


Figure C115 Arc's cathode voltage at 100 Amps.

CH1↓ 50 V (Avg 193 V)
A 2 ms 50.30 V LINE Avg:128



CH1↓ 50 V
A 2 ms 50.30 V LINE Env:256

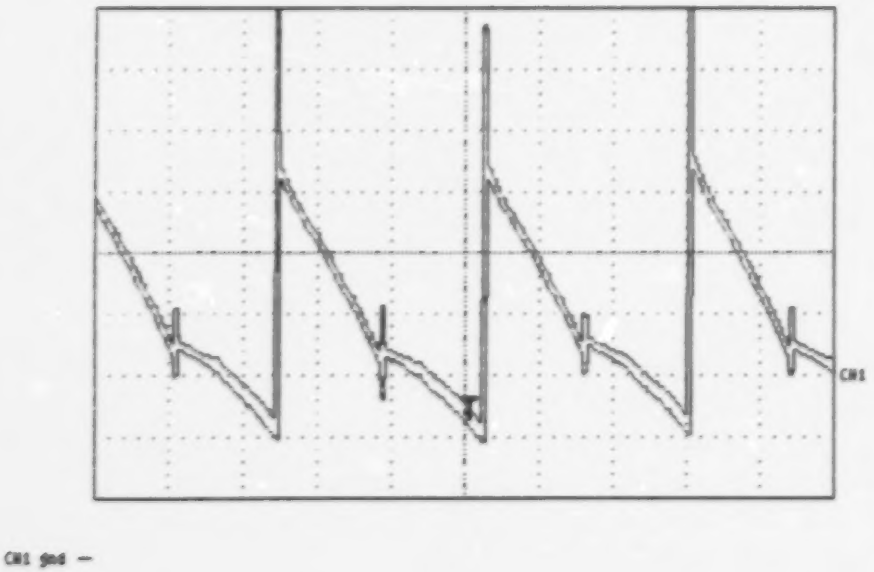
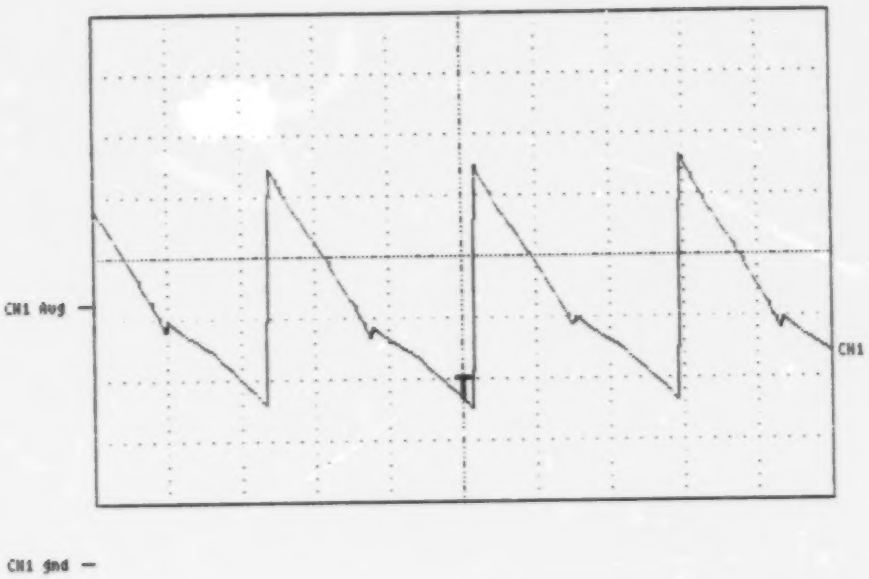


Figure C116 Arc's cathode voltage at 150 Amps.

CH1↓ 50 V (Avg 210 V)
A 2 ms 50.30 V LINE Avg:128



CH1↓ 50 V
A 2 ms 50.30 V LINE Env:256

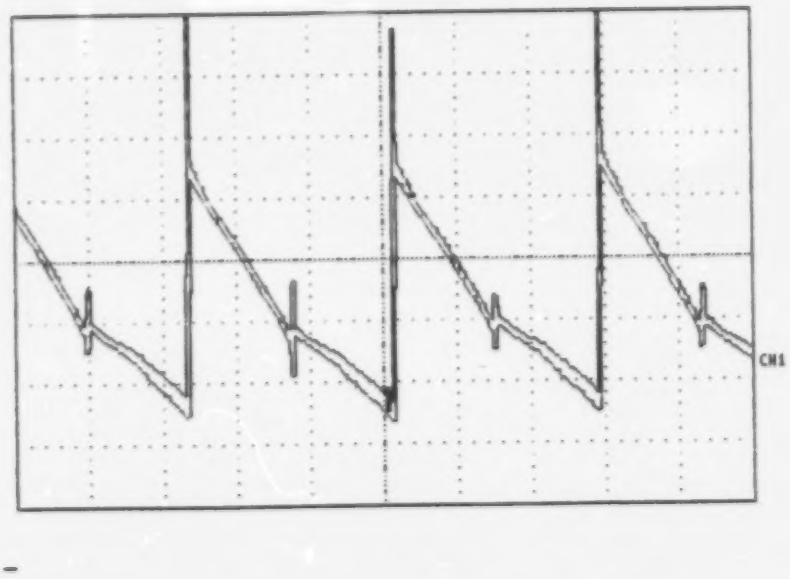
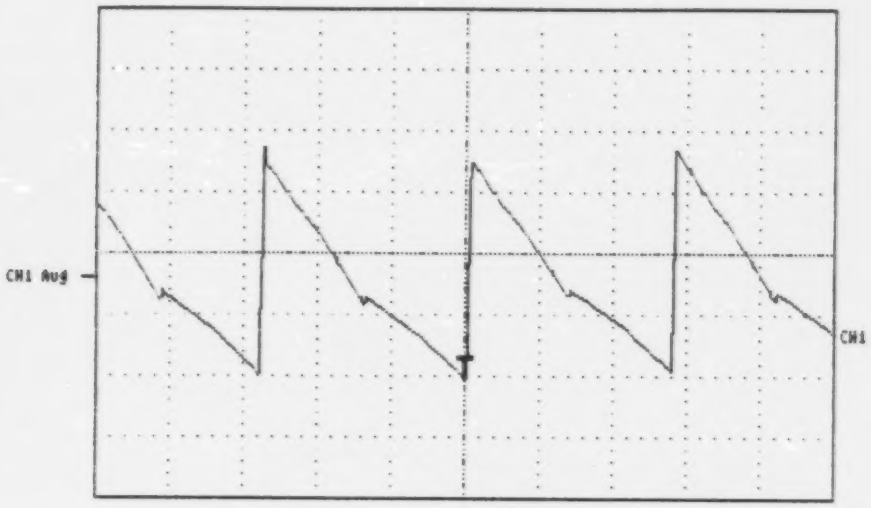


Figure C117 Arc's cathode voltage at 200 Amps.

CH1↓ 50 V (Avg 227 V)
A 2 ms 50.30 V LINE Avg:128



CH1↓ 50 V
A 2 ms 50.30 V LINE Env:256

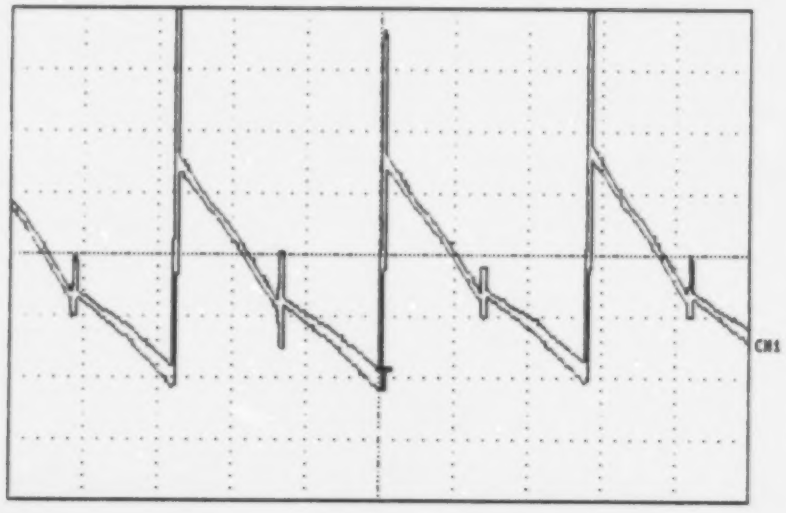
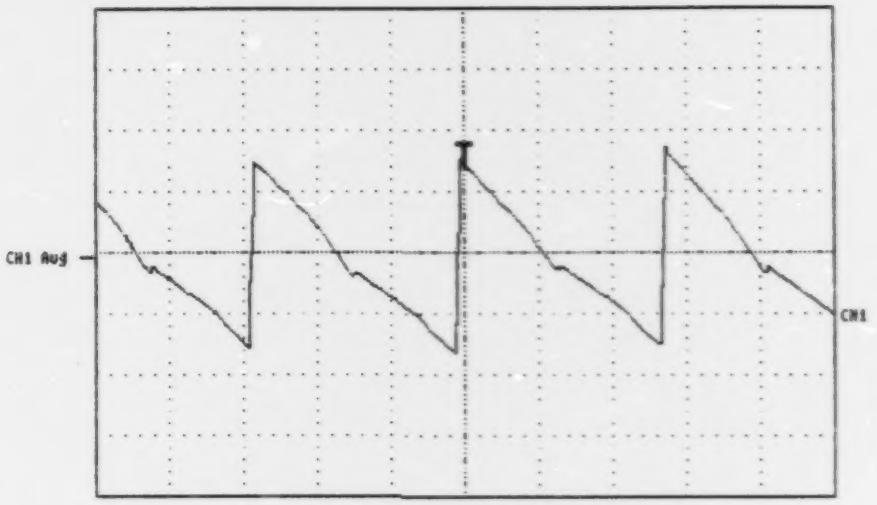


Figure C118 Arc's cathode voltage at 250 Amps.

CH1↓ 50 V (Avg 243 V)
A 2 ms 50.30 V LINE Avg:128



CH1↓ 50 V
A 2 ms 50.30 V LINE Env:256

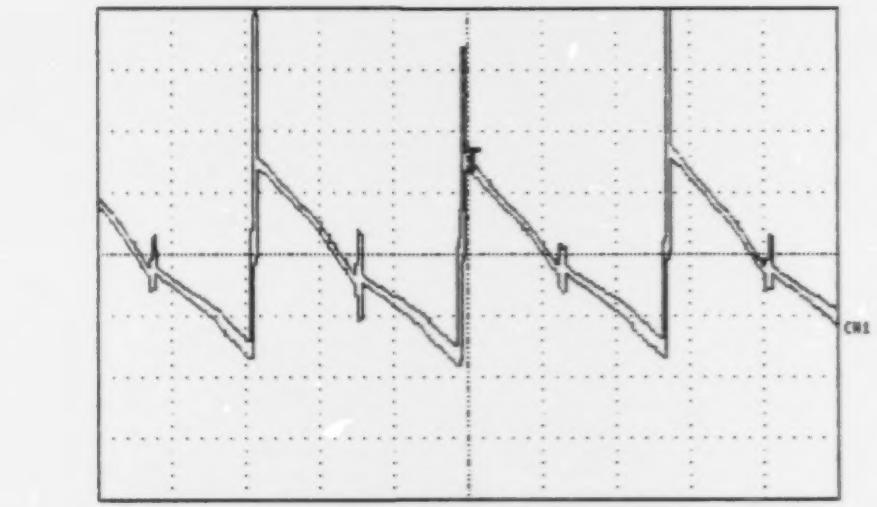
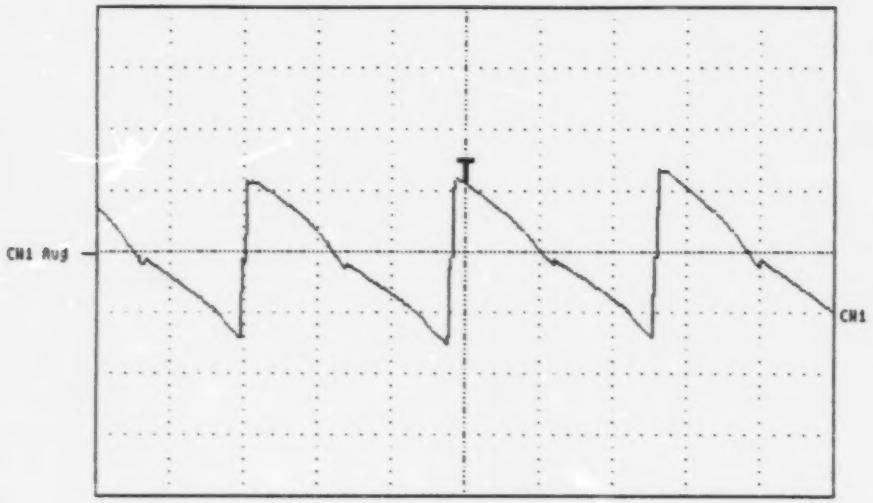


Figure C119 Arc's cathode voltage at 300 Amps.

CH1↓ 50 V (Avg 257 V)
A 2 ms 50.30 V LINE Avg:128



CH1↓ 50 V
A 2 ms 50.30 V LINE Env:256

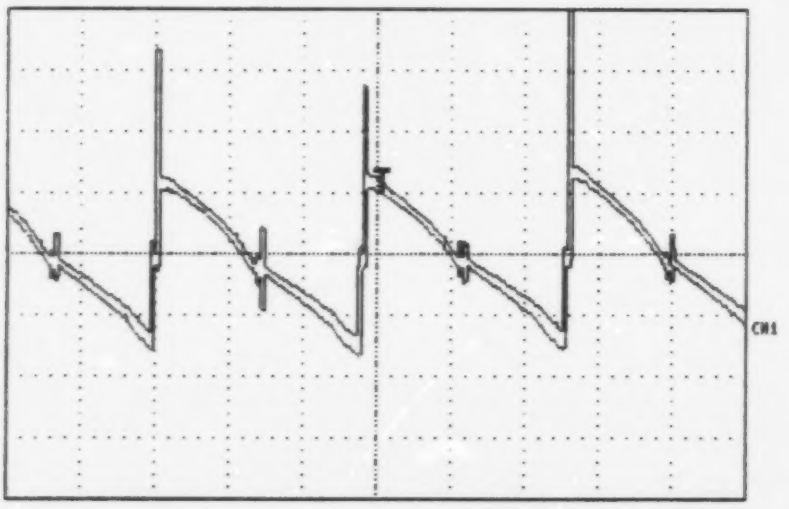
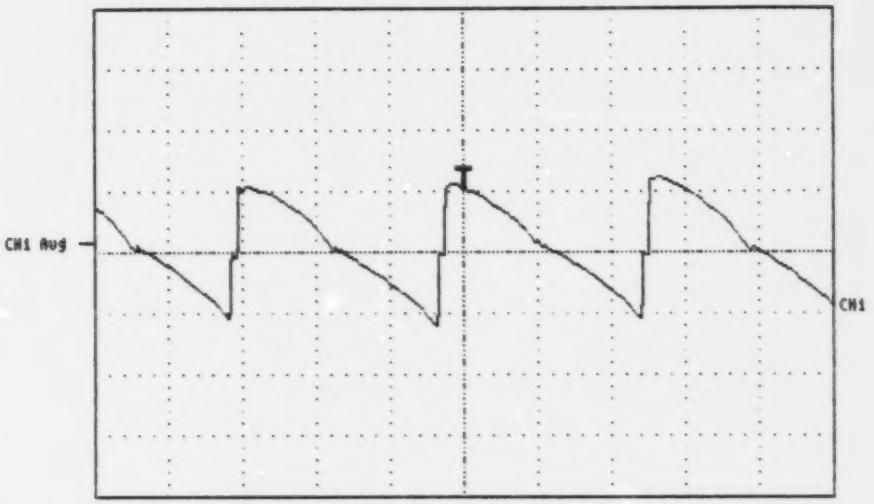


Figure C128 Arc's cathode voltage at 350 Amps.

CH1↓ 50 V (Avg 267 V)
A 2 ms 50.30 V LINE Avg:128



CH1↓ 50 V
A 2 ms 50.30 V LINE Env:256

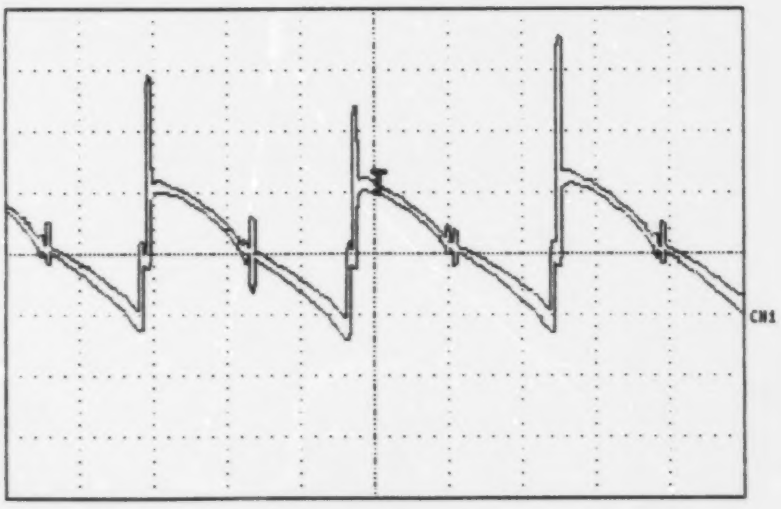
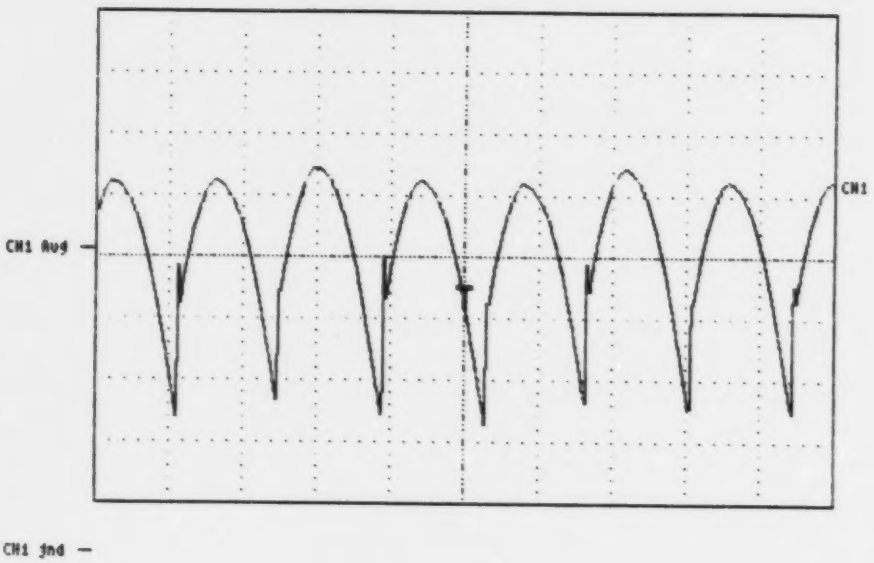


Figure C121 Arc's current at 100 Amps.

CH1 200 mV (Avg 987 mV)
A 2 ms 50.30 V LINE Avg:128



CH1 200 mV
A 2 ms 50.30 V LINE Env:256

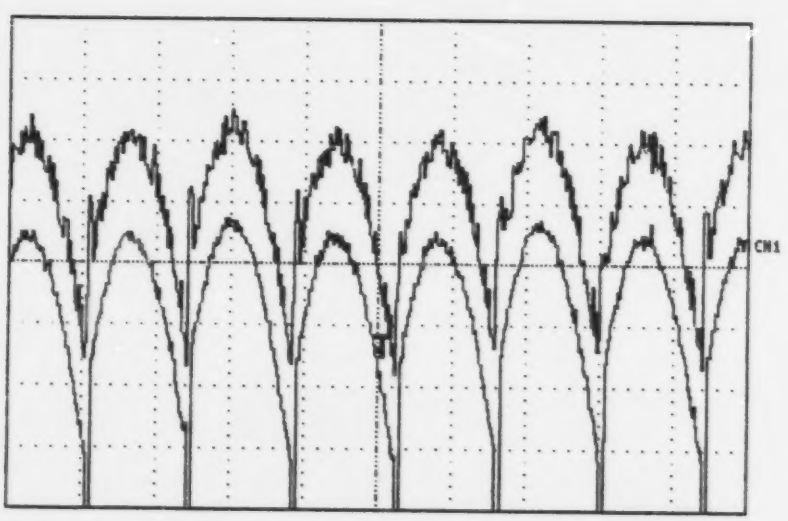
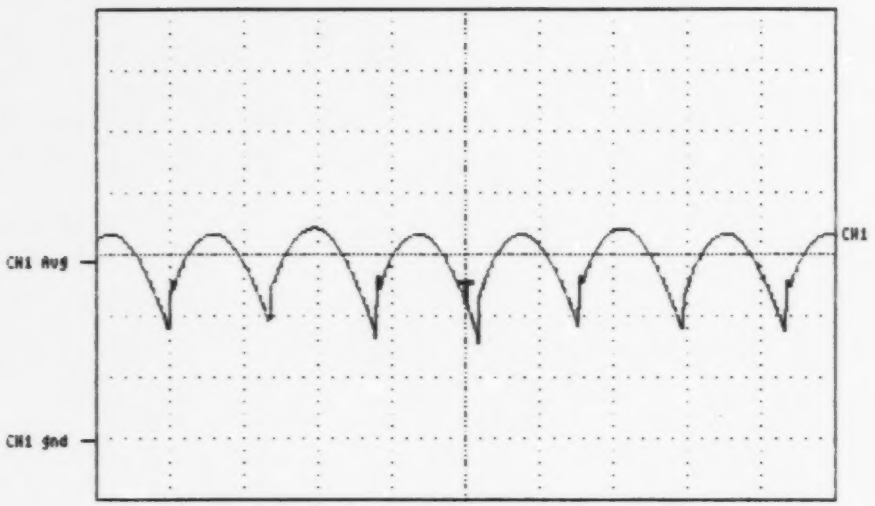


Figure C122 Arc's current at 150 Amps.

CH1 500 mV (Avg 1.47 V)
A 2 ms 50.30 V LINE Avg:128



CH1 500 mV
A 2 ms 50.30 V LINE Env:256

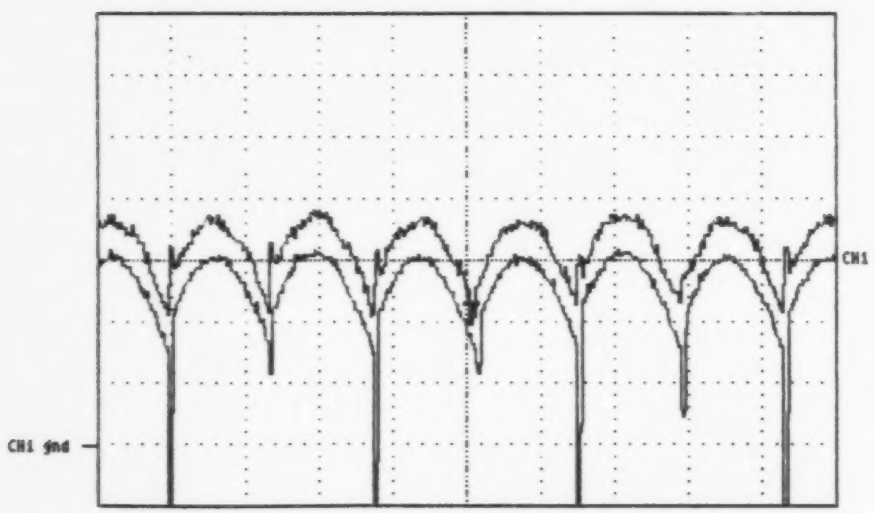
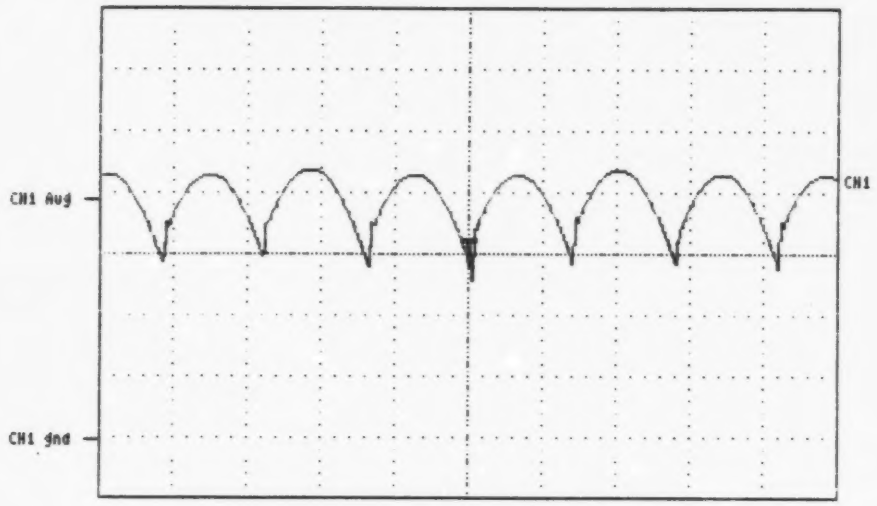


Figure C123 Arc's current at 200 Amps.

CH1 500 mV (Avg 1.96 V)
A 2 ms 50.30 V LINE Avg:128



CH1 500 mV
A 2 ms 50.30 V LINE Env:256

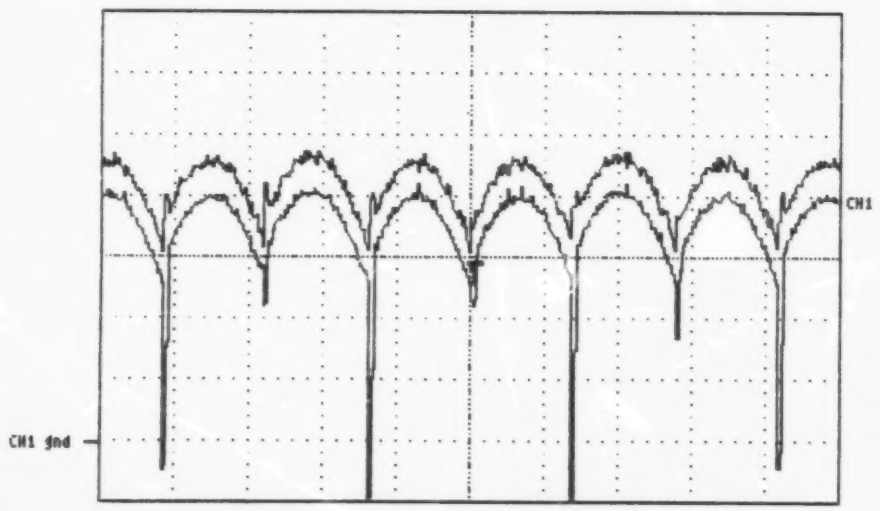
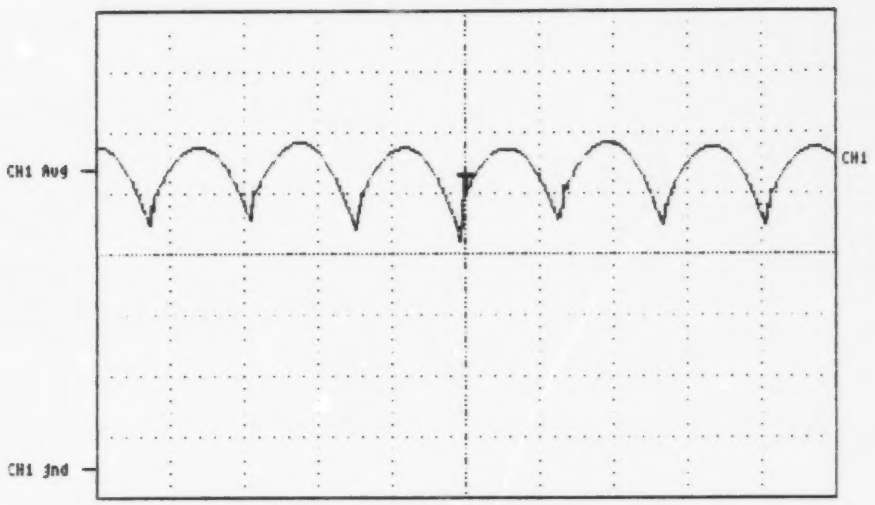


Figure C124 Arc's current at 250 Amps.

CH1 500 mV (Avg 2.45 V)
A 2 ms 50.30 V LINE Avg:128



CH1 500 mV
A 2 ms 50.30 V LINE Env:256

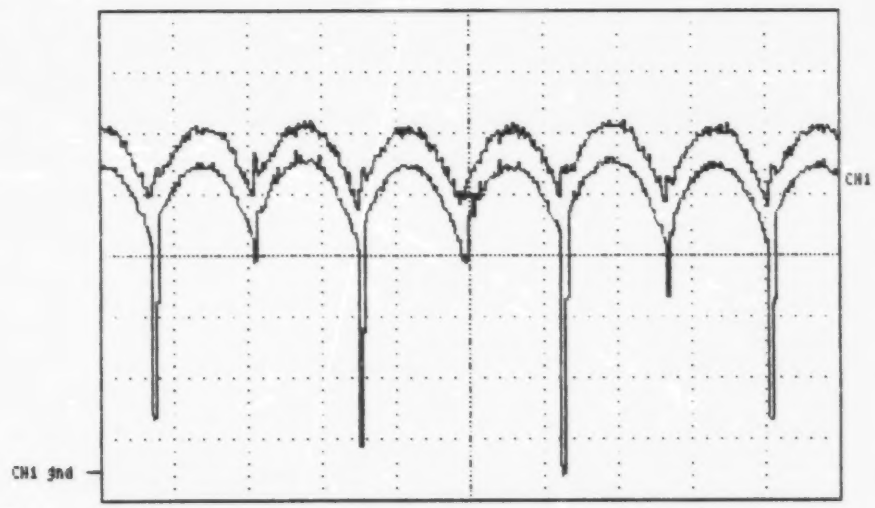
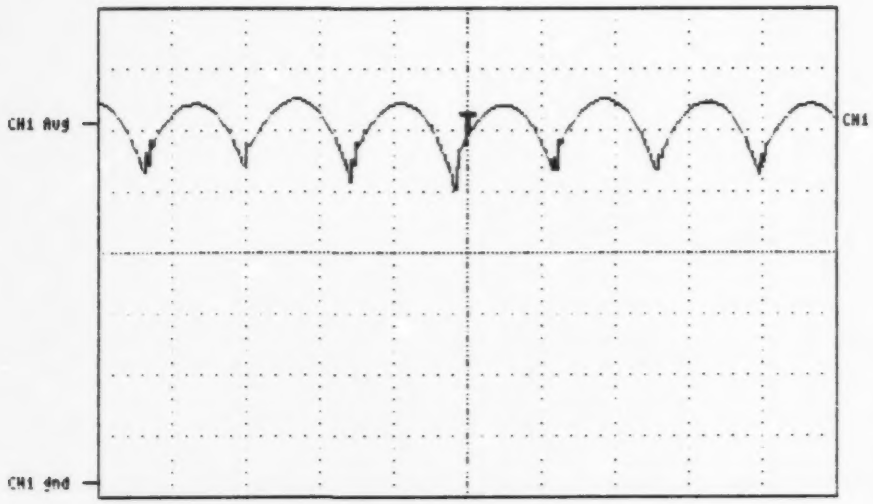


Figure C125 Arc's current at 300 Amps.

CH1 500 mV (Avg 2.94 V)
A 2 ms 50.30 V LINE Avg:128



CH1 500 mV
A 2 ms 50.30 V LINE Env:256

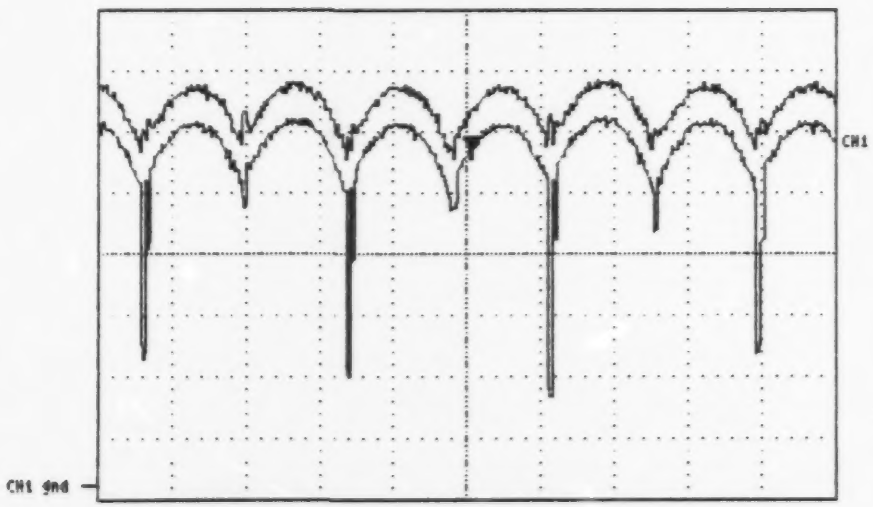
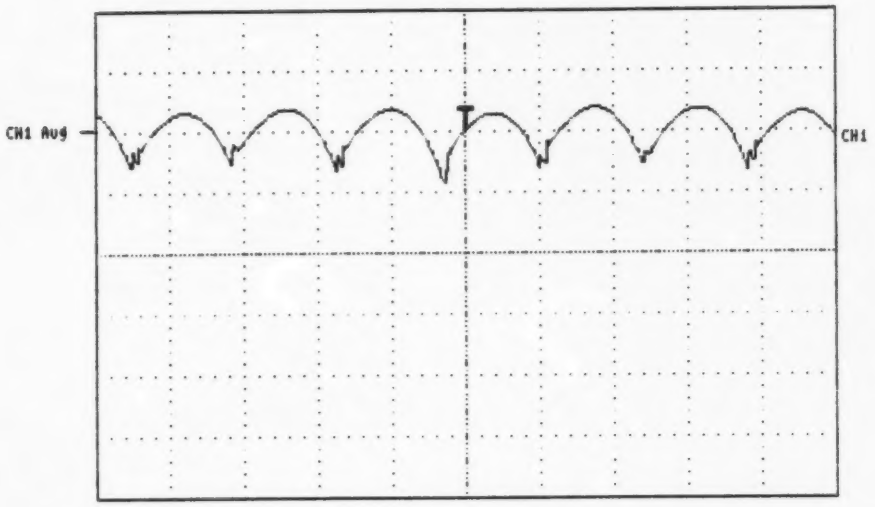


Figure C126 Arc's current at 350 Amps.

CH1 500 mV (Avg 3.43 V)
A 2 ms 50.30 V LINE Avg:128



CH1 500 mV
A 2 ms 50.30 V LINE Env:256

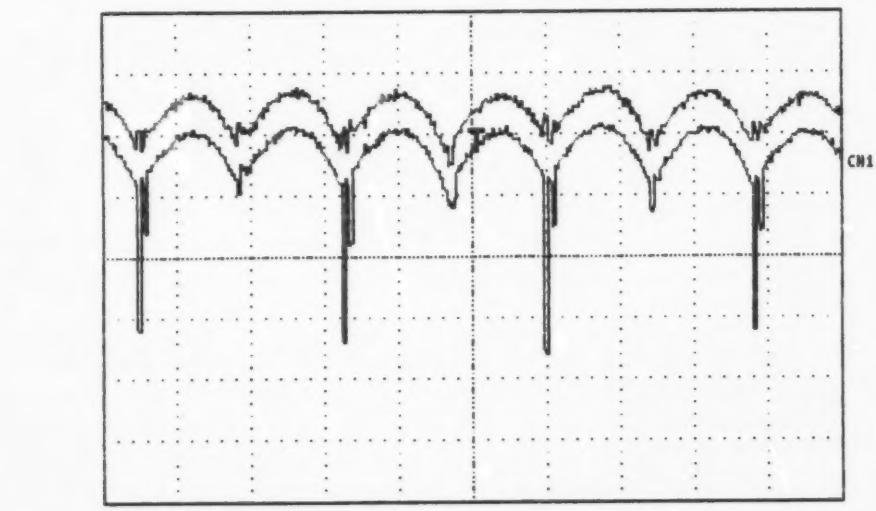
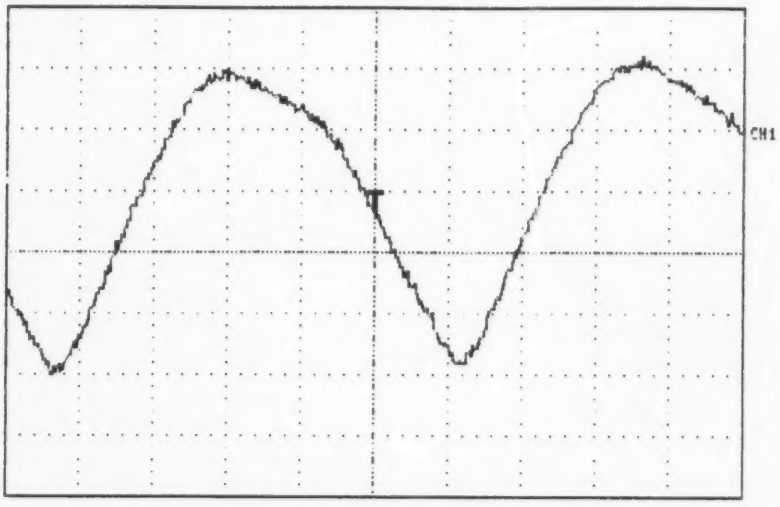


Figure C127 Noise on the light intensity signal (100 A.)

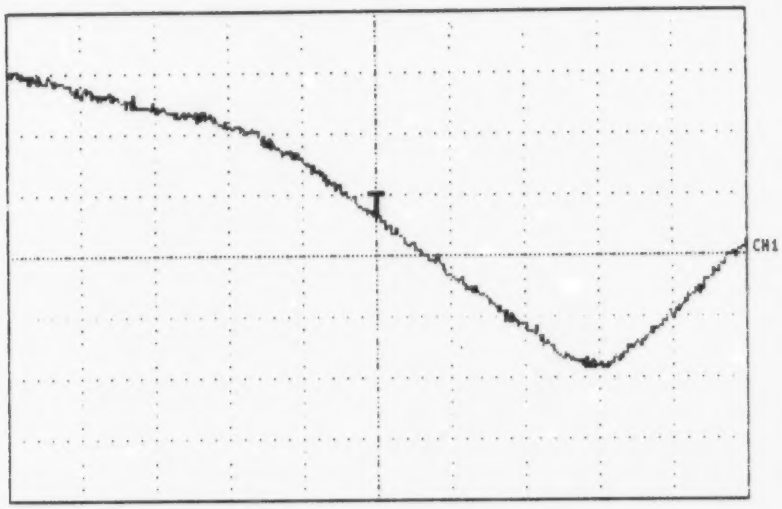
CH1 2 mVΩ
A 500 us 50.30 V LINE



CH1 gnd —

Figure C128 Noise on the light intensity signal (100 A.)

CH1 2 mVΩ
A 200 us 50.30 V LINE



CH1 gnd —

APPENDIX D

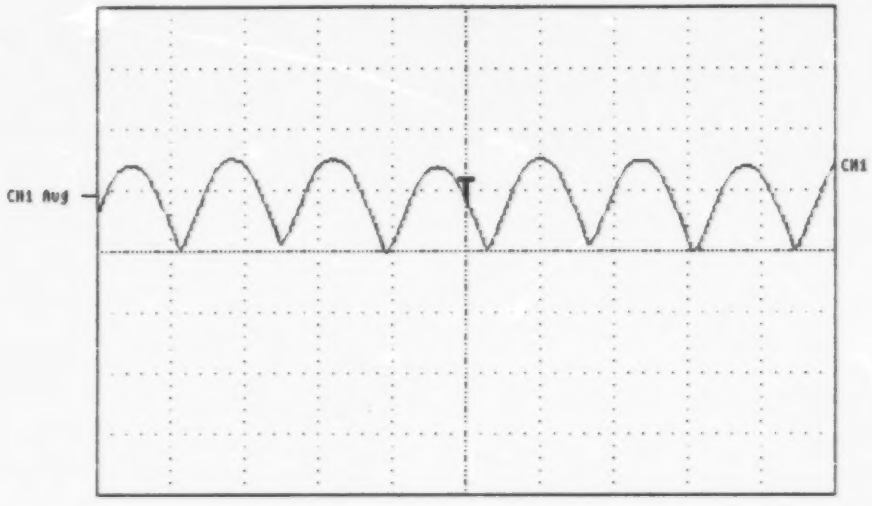
DATA ON THE 11 mH INDUCTOR EXPERIMENT

APPENDIX D

Two Hammond 5 mH 50 Adc (195G50) (Rs = 0.021Ω) inductors were added in series to the existing 1 mH 350A inductor to determine whether the arc lamp would start and the effect of increasing the inductance on the ripple. The increased impedance between the arc and the SCR's proved not to affect the starting ability of the lamp. The effect of the inductance on the light intensity ripple was measured as described in Section 7.3.1. The results are given in Figures D1 to D5. The equivalent ripple reduction factor was 3.3 which is far from the theoretical factor of 10.9 (Section 9.6). As the 50A inductors were saturated at 100A, the effective total inductance value of the two 50A inductors was probably 2.5 mH when using the 3.3 reduction factor and equation 7.

Figure D1 Light intensty @ 100 A. with 11 mH (10 in. up; cente)

CH1 2 mVΩ (Avg 11.7 mV, Max 12.9 mV, Min 9.80 mV, Rip 26.6%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mVΩ (Maxima(7): δMax 1.20 mV(10.2%), δAvg 1.10 mV(9.4%))
(Minima(7): δMax 1.20 mV(10.2%), δAvg 1.14 mV(9.8%))
A 2 ms 50.30 V LINE Env:256

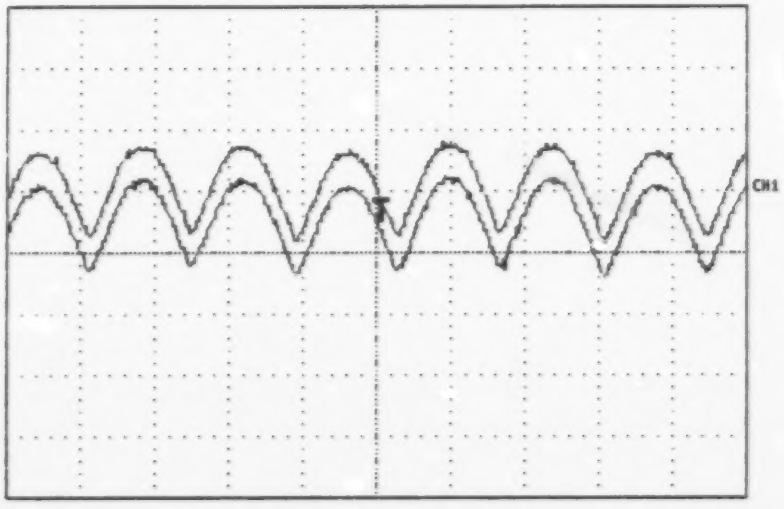
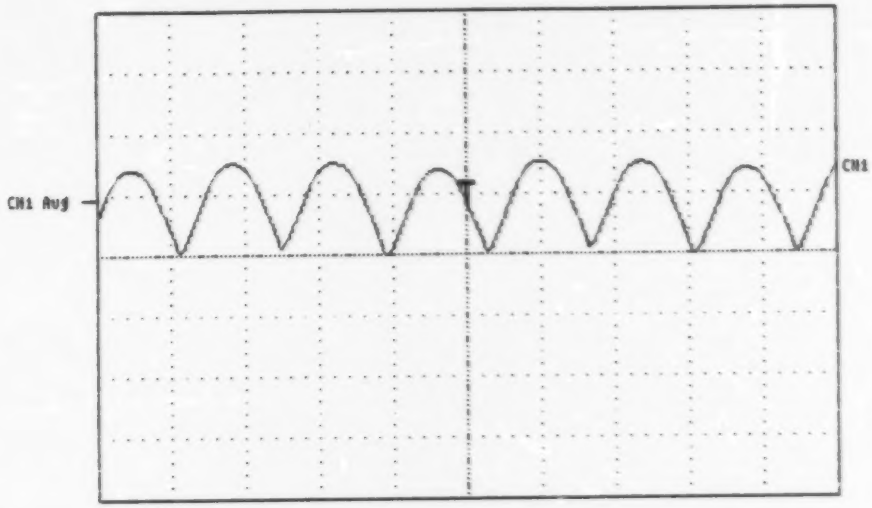


Figure D2 Light intensty @ 100 A. with 11 mH (18 in. up; cente)

CH1 2 mVΩ (Avg 11.7 mV, Max 12.9 mV, Min 9.88 mV, Rip 26.6%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mVΩ (Maxima(7): δMax 1.20 mV(18.2%), δAvg 1.12 mV(9.5%))
(Minima(7): δMax 1.20 mV(18.2%), δAvg 1.12 mV(9.5%))
A 2 ms 50.30 V LINE Env:256

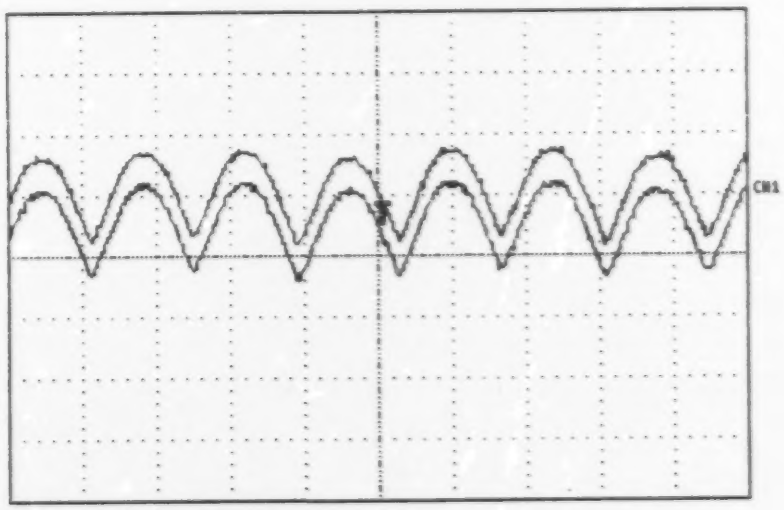
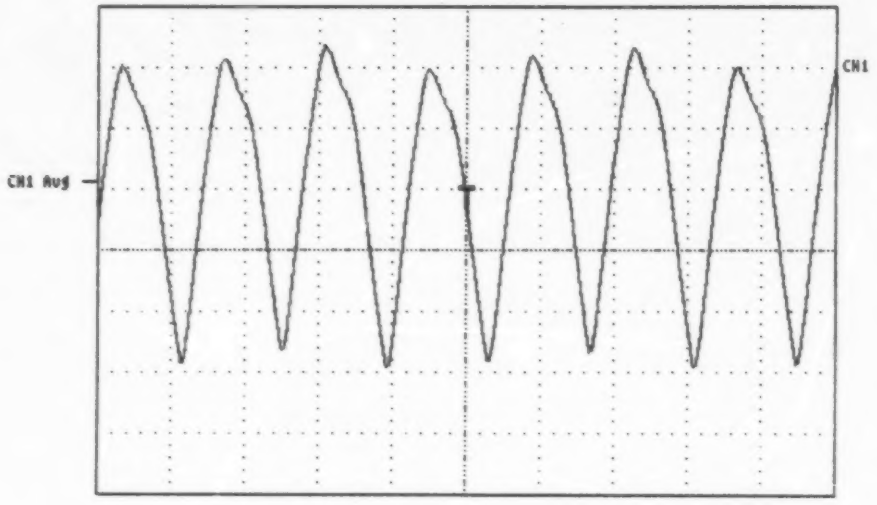


Figure D3 Light intensty @ 100 A. with 1 mH (18 in. up; cente)

CH1 2 mVΩ (Avg 12.1 mV, Max 16.6 mV, Min 6.84 mV, Rip 87.3%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mVΩ (Maxima(7): δMax 1.68 mV(13.9%), δAvg 1.44 mV(11.9%))
(Minima(7): δMax 1.52 mV(12.6%), δAvg 1.38 mV(11.4%))
A 2 ms 50.30 V LINE Env:256

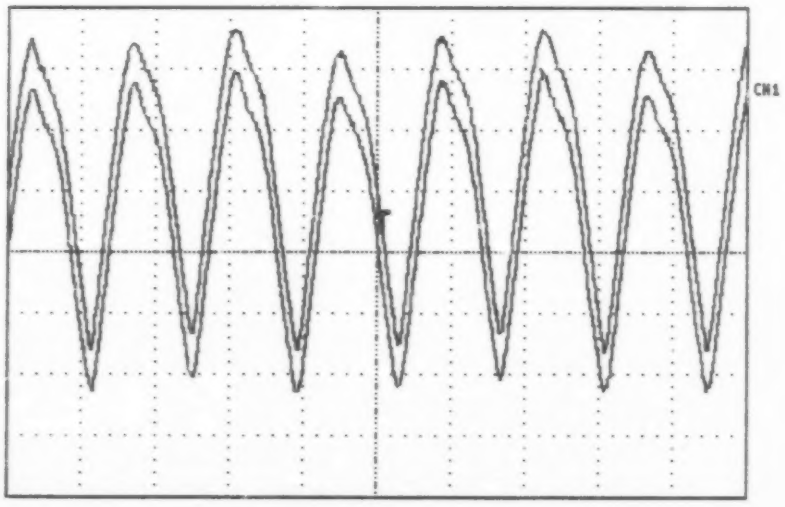
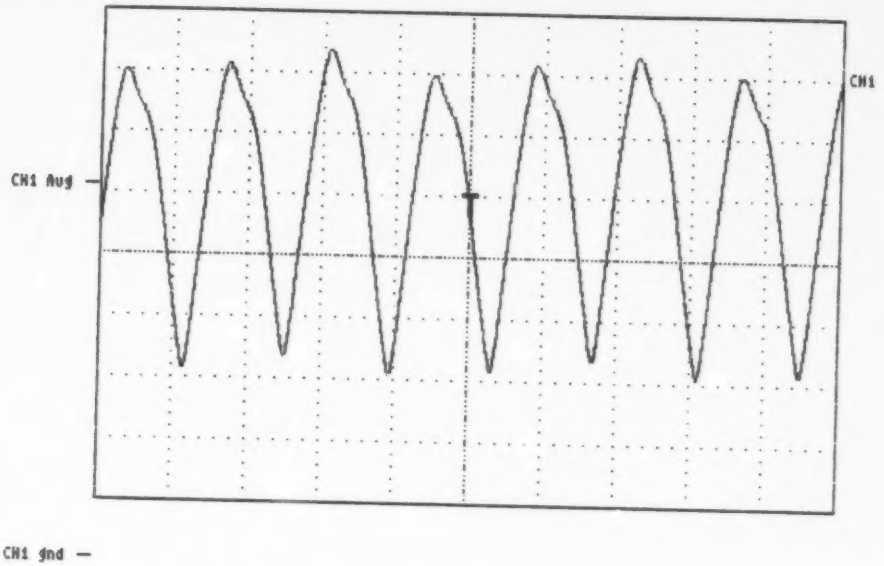


Figure D4 Light intensty @ 100 A. with 1 mH (18 in. up; cente)

CH1 2 mVΩ (Avg 12.1 mV, Max 16.6 mV, Min 6.04 mV, Rip 87.4%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mVΩ (Maxima(7): δMax 1.68 mV(13.9%), δAvg 1.58 mV(13.0%))
(Minima(7): δMax 1.60 mV(13.2%), δAvg 1.45 mV(12.0%))
A 2 ms 50.30 V LINE Env:256

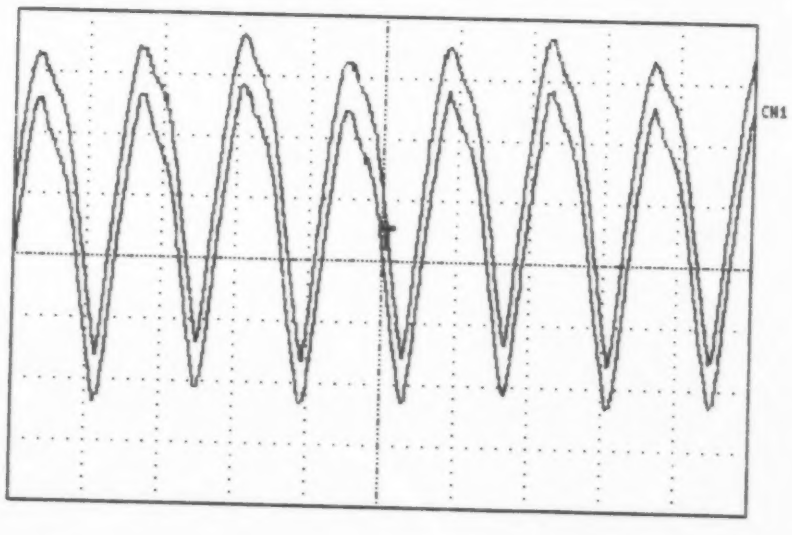
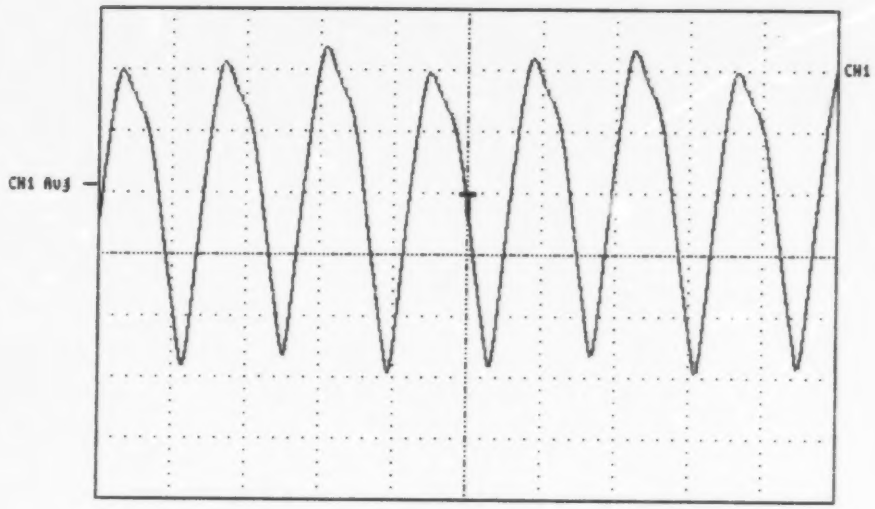
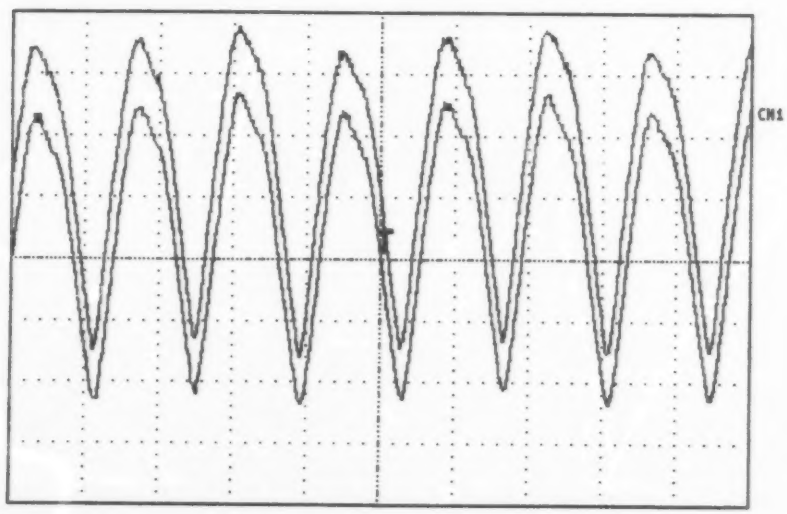


Figure D5 Light intensty @ 100 A. with 1 mH (18 in. up; cente)

CH1 2 mVΩ (Avg 12.1 mV, Max 16.6 mV, Min 6.84 mV, Rip 87.2%)
A 2 ms 50.30 V LINE Avg:128



CH1 2 mVΩ (Maxima(7): δMax 2.24 mV(18.5%), δAvg 2.08 mV(17.2%))
(Minima(7): δMax 1.84 mV(15.2%), δAvg 1.65 mV(13.6%))
A 2 ms 50.30 V LINE Env:256



ONTARIO **RESEARCH**
FOUNDATION

Energy

energy conservation programs and analyses, thermal insulation design and evaluation, waste heat recovery, building energy systems and monitoring, heat storage systems and materials, thermoelectric generation, combustion technology, burner development, heat transfer analysis, solar systems monitoring, National Solar Test Facility, solar technology, wind power, coal, lignite and oil sands processing, alternate fuel utilization, battery and fuel cell technology, peat processing and utilization, fenestration measurements, heat pump development and test facilities, residential heating systems, air to air heat exchange test facility, photovoltaic devices, . . .

Environment

ambient air quality assessment, environmental impact assessments, long-range transport of atmospheric pollutants, precipitation chemistry, particulate characterization studies, emission inventories, source sampling, odour emission and control, asbestos measurement and control, occupational health and safety studies, diesel emission control technology, air pollution control, pesticide residues, trace metal analysis, trace organic analysis, radionuclide analysis, mutagenic testing, noise and vibration analysis, radiation measurements, particulate identification and measurement, water surveys, water purification, industrial and municipal wastewater treatment, membrane separation techniques, wet oxidation, solid waste treatment and recovery, hazardous waste treatment and disposal, indoor air quality assessments, priority pollutant analysis, landfill technology, . . .

Materials

building materials, plastics, composites, metals, glass and ceramics, wood and wood composites, biomaterials, adhesives and printing inks, fibres, yarns, fabrics and geotextiles, leather, organic and inorganic chemicals, specification development, quality assurance, mechanical, chemical and thermal properties, test method development, failure analysis, fire and flammability, glass-metal seals, metal and alloy powders, metallography, materials characterization, materials characterization by optical and electron microscopy and X-ray microanalysis, photovoltaic materials, materials corrosion resource centre, corrosion properties and control, bacterial corrosion, coatings and sealants, rubber technology, X-ray analysis, cement and concrete, soils and aggregates, gypsum, body armour testing, footwear, paper-making materials, roofing and waterproofing, waste material stabilization and solidification, . . .

Products & Processes

clothing, footwear and industrial textile products, knitting technology, thin and thick film systems, microelectronics development, fibre optics, instrumentation, bioengineering, ultrasonic and fluid shear devices, microwave drying, transportation and equipment testing, mathematical stress and vibration analysis, product, equipment and machinery design & development, fuel emulsification, organic analysis and characterization, chemistry of foodstuffs, pulp and paper processes, ceramics processing, metallurgical process development, powder metal technology, packaging applications, technical and economic evaluations, industrial engineering applications, process control, enzyme analysis, electrical testing, radioactive surveys, industrial microbiology, biotechnology, technical and management skills development seminars, paper products, absorbent consumer products, detergent and cosmetic formulation, metal chemical analysis, flash hydropyrolysis of coal, electroplating, . . .

Resources

mineral processing, hydro and pyrometallurgical processing of ferrous and non-ferrous ores, coal evaluation, coal ash utilization and product development, asbestos processing and applications, non-metallic minerals/industrial minerals processing and utilization, uranium processing, forest utilization, utilization of forest and agricultural wastes, utilization of industrial, mining and domestic wastes, energy and chemicals from biomass, in-plant waste reduction, mineralogical services, mining and metallurgical waste disposal, . . .

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